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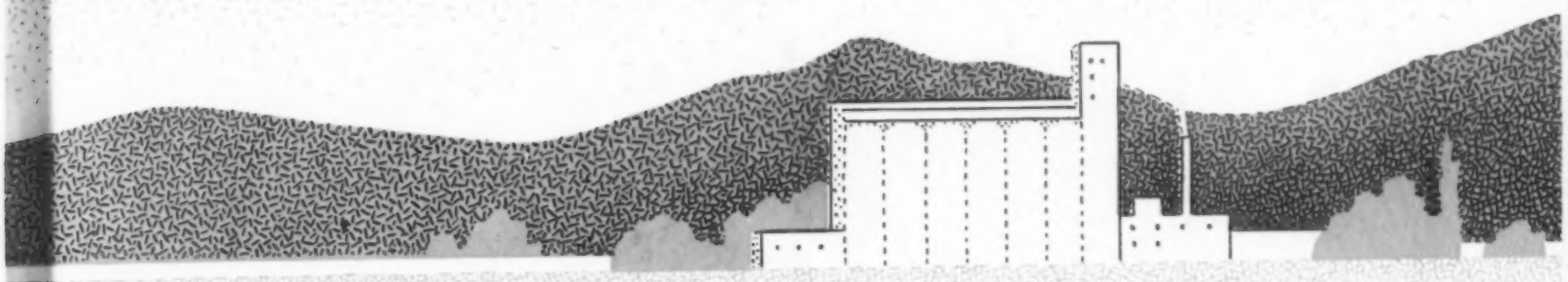
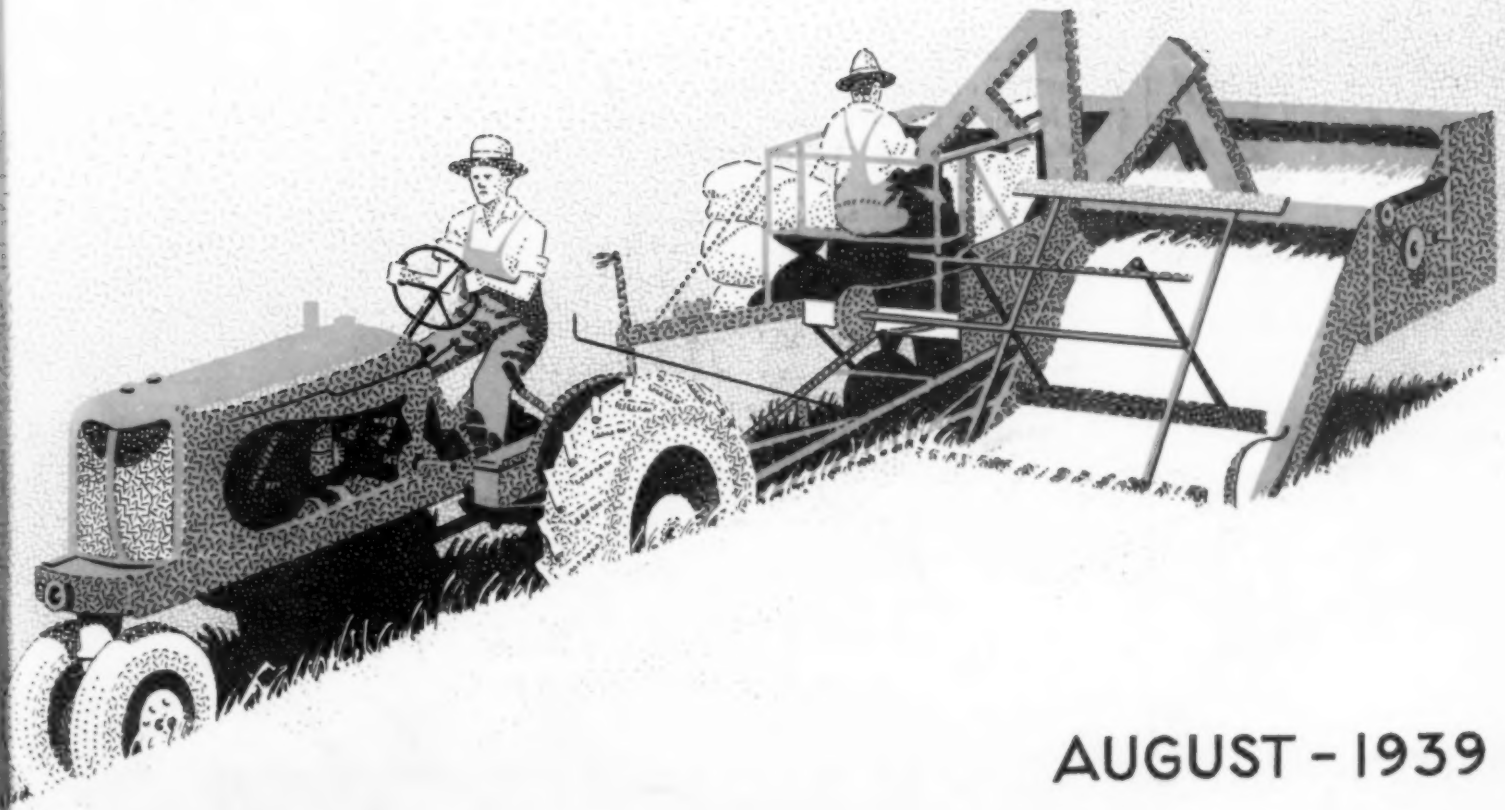
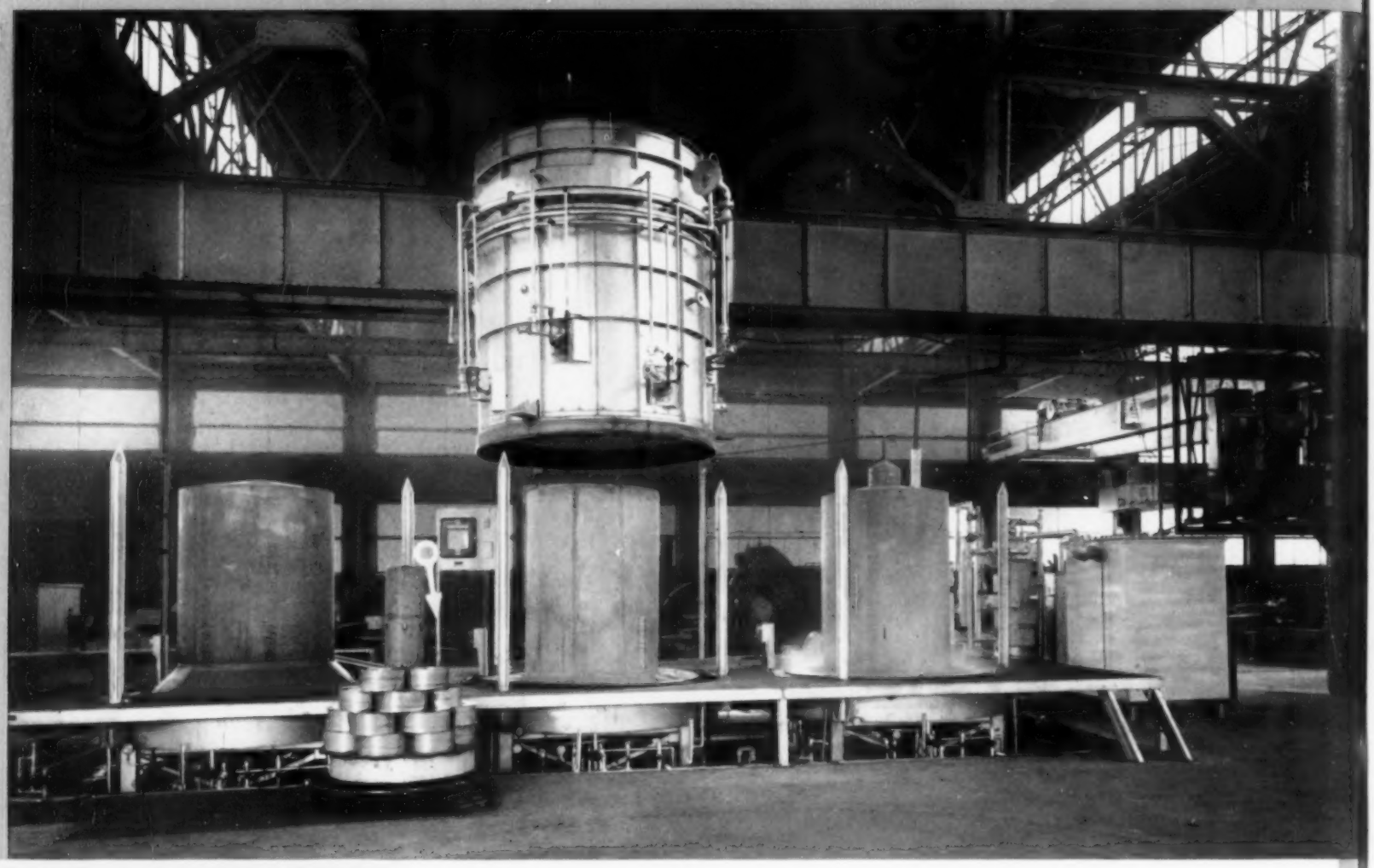
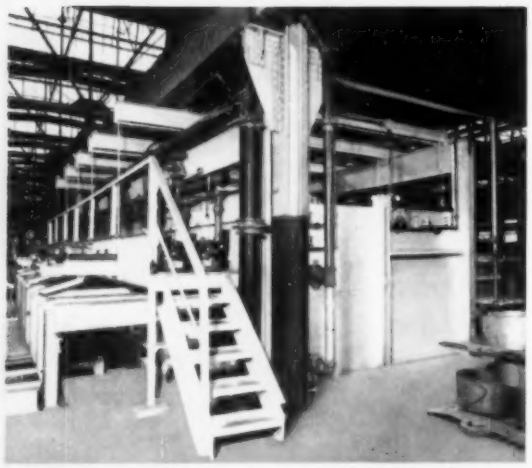




AUGUST - 1939

THESE NEW SC COPPER AND BRASS FURNACES ASSURE ACCURATE GRAIN SIZE CONTROL





● In the annealing of copper and brass strip for deep drawing it is essential that the grain size be controlled very closely. Especially is this true of the finish anneal since no subsequent rolling and equalization of grain size takes place. In the direct-fired, controlled atmosphere, bell type furnace (shown above) for bright annealing copper and clean annealing brass, a series of 27 consecutive heats ranging from 850° F. to 1150° F. showed a maximum variation in grain size of only ± .0025 millimeters between top, center, and bottom coils of the individual heats. Only five heats showed this maximum variation; ten heats showed no variation at all and the remainder less than ± .0025 mm. Tests of the recirculated air furnaces (lower left) showed similar uniformity of grain size.

On the breakdown anneal, control of grain size has facilitated rolling. In the new SC slab heating furnace (upper left) with automatic loading table and automatic discharge, slabs are conveyed through the furnace by a walking-beam conveyor mechanism and heated only one high to assure uniform heating and grain size. Write for additional information.

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METAL PROGRESS

AUGUST, 1939 VOLUME 36, NO. 2

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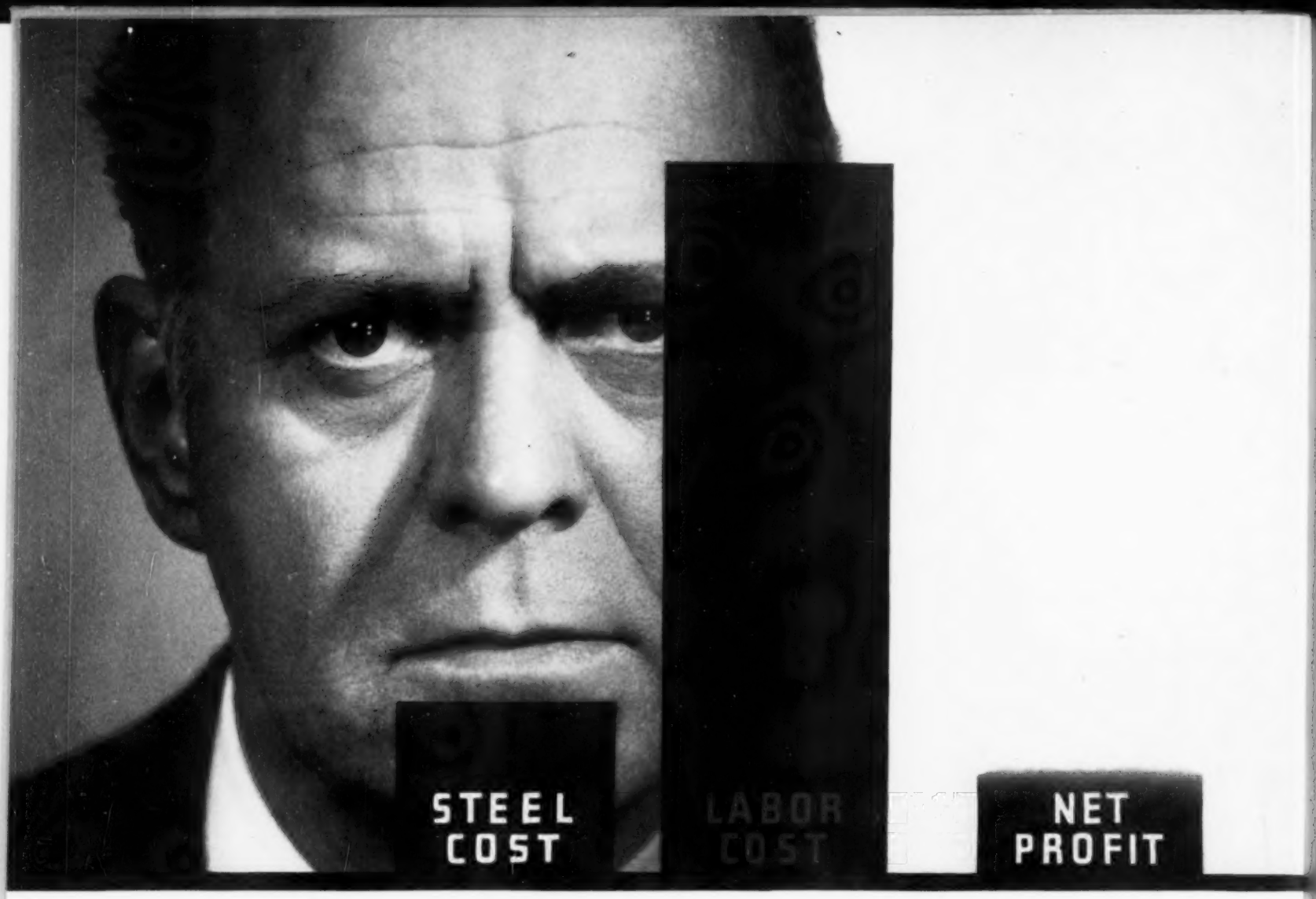

Consider Labor Costs When Buying Steel

On most jobs, shop labor costs are the biggest single factor—and they depend to a large degree on the steel used. If bars are too hard for bending or forming—or have hard spots to break or dull tools—if some shapes are not straight—or if in the case of alloy steel the required properties are not developed by the first heat treatment—then up go costs, down go profits.

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Elwood Haynes, pioneer American automobile manufacturer, made alloys of nickel and chromium in 1899 by reducing their oxides with aluminum, and found them to be highly resistant to chemical attack. Other mixtures with cobalt and tungsten followed, in a search for durable spark plug electrodes. By 1913 the worth of some of these alloys as cutting tools had been discovered. Today several types of cobalt-chromium-tungsten alloys are marketed as "stellite", a name referring to their star-like color and permanence, and used as forgings, castings, or welded-on facings which need superior hardness, wear and corrosion resistance

ALLOYS OF COBALT, CHROMIUM, AND TUNGSTEN

A REVIEW BY WILLIAM A. WISSLER
Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

ALLOYS of cobalt, chromium, and tungsten are an outgrowth of early experiments with alloys of the nickel-chromium system. In 1899, the late Elwood Haynes, the inventor of these alloys, produced one consisting of practically pure chromium and nickel by heating their mixed oxides with aluminum. This alloy, when polished, retained its luster even in the atmosphere of the chemical laboratory, and proved to be "insoluble" in nitric acid, even when boiling. It was malleable, and with proper annealing it could be worked into sheets and wire.

Shortly afterward, Haynes began a series of experiments which consisted of reducing a mixture of the oxides of cobalt and chromium with powdered aluminum, and secured a few beads of metal which not only showed the same untarnishable properties as the nickel-chromium alloy, but possessed much greater hardness. He believed that this new alloy might be used for making non-corrodible tools or knives. The alloy could not be worked to any extent, but was found to be malleable at a bright orange heat. This investigation was temporarily dropped, but it was taken up again in 1905 with the idea of using the alloy for ignition points on gas engines. Larger quantities were made, and in 1906 sufficient quantities were made to determine that alloys containing 75% of cobalt and 25% of chromium could be forged and rolled to a limited degree, although the hardness of the metal made these operations rather difficult.

In 1907, a patent was granted on cobalt-chromium alloys that would be suitable for tableware, surgical instruments, laboratory equipment, analytical weights, and other applications, and also for cutting tools to be used on relatively soft materials. A cutting blade was made of the alloy which took an edge comparable to that of tempered steel.

A few years later Haynes added tungsten and molybdenum to the cobalt-chromium base. This made the alloy so hard that he decided to try it as a tool for machining cast iron. As he was at that time associated with the Haynes Automobile Co., the operator of a boring mill was asked to try the new tool on cast iron pistons. At about two o'clock in the afternoon the machinist stopped the mill, and, upon being questioned, said that he had already finished his normal day's work and had nothing more to do; the new tool had cut so much faster that the production per unit of time had been increased about 50%! This and other tests showed that these cobalt-chromium-tungsten cutting tools were much superior to any then available, and in 1913 they were placed on the market.

Because these alloys were lustrous and

practically unaffected by atmospheric corrosion they were given the name "stellite" (from the Latin word *stella* meaning star). Generally speaking, the cobalt-chromium-tungsten alloys possess three distinctive properties, namely:

1. They are untarnishable under atmospheric conditions, and immune to many chemical reagents.
2. They possess considerable hardness.
3. They retain their hardness up to visible redness.

Some of the stellite articles for ordinary use were originally formed from alloys of cobalt and chromium only. The softer alloys were used for table knives or spoons. The harder edged tools, such as surgical instruments, contained, in addition to cobalt and chromium, a certain amount of tungsten to give them greater hardness, while in other instances a small amount of iron or nickel was introduced into the alloy to soften it so that it could be more readily worked.

When iron was added to the alloy, the resultant mixture was termed "festel" metal, the name being coined from the chemical symbol for iron, Fe, and the first syllable of "stellite".

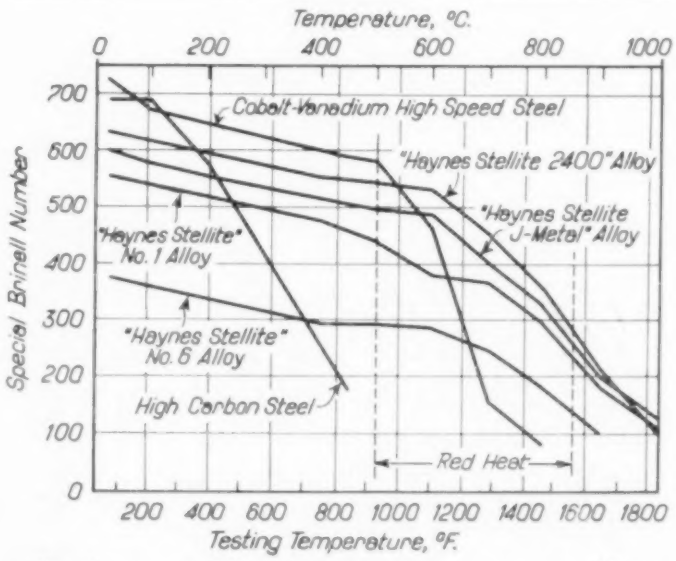
Some of the stellite alloys developed for cutting tools during the War showed a remarkable resistance to chemical reagents. One of these, possessing a high chromium content, could be given a magnificent polish. It was slowly attacked by cold hydrochloric acid, but it was practically immune to cold concentrated sulphuric acid, and nearly immune to dilute sulphuric acid. It resisted nitric acid of all strengths. Its use for balance weights was therefore suggested. Weights made of this material retained their luster under the most trying conditions, and were so hard that their loss from ordinary wear would probably be unweighable for several years. They have, however, never been made commercially.

During the War, two of the cobalt-chromium-tungsten alloys played an important role in the high production of shells. At one plant, under contract to produce one 9½-in. shell a minute for the British Government, a choke point developed at one of the major operations in the finish-turning. To correct the situation with cutting tools then in use would have necessitated the installation of new equipment, and for lack of space this would have dislocated 20 subsequent operations. Eventually, tools of the new alloy were tested, and the cutting time was decreased about 50% and production of the machines increased 30%, and as soon as all machines on this operation were equipped the congestion was relieved. The new tools were so prized by the piecework operators that many kept a supply in their pockets. Some even wanted to buy the metal so that they would be assured of high daily earnings.

Because of its striking characteristics, this alloy was tested for many uses. Among these were cloth and rubber cutting knives, fruit slicing and skinning knives, rollers, gages, heat resisting scrapers, valves, valve seats, glass molds, bearings, bushings, scale pivots, and numerous other parts operating under abrasion or corrosion. Scientific mirrors were made and found to be very useful for high reflectivity, permanence of shape, and non-tarnish surface. Experiments were made on ball bearings, and for bearings exposed to salt water and without lubrication.

Hard Facing — As early as 1915, the alloy was being used to tip certain types of tools, and about seven years later the hard facing process was in general use to protect wearing parts of all kinds (see METAL PROGRESS, October 1935). As welded coatings could effectively protect all surfaces subject to abrasion, hard facing proved to be very economical and is now used throughout industry.

In many applications it became apparent that something other than the commonly deter-



Hardness at Elevated Temperatures of Alloys Used for Cutting Tools and for Wear Resistance. Sample was surrounded by furnace, heated 30 min. at temperature, trap opened, and Brinell indentation quickly made with carbide ball

mined physical properties was responsible for its excellence as metal-cutting tools and its long life under abrasive conditions. Extensive tests showed that these alloys lasted longer under abrasion than other metals of even greater hardness. These peculiarities could be attributed to the property of "red hardness". When the hardness is measured at room temperature by resistance to indentation, as in the conventional Brinell or Rockwell methods, cobalt-chromium-tungsten cutting tools are not as hard as hardened high speed or hardened high carbon steel tools, but unlike iron-carbon alloys they have no critical or transformation points and do not exhibit the phenomenon of "tempering". Their hardness is inherent, the result of the composition and the method of manufacture, and the harder grades, once cast, cannot be permanently softened unless they are heated almost to the melting point, which is about 2300° F.

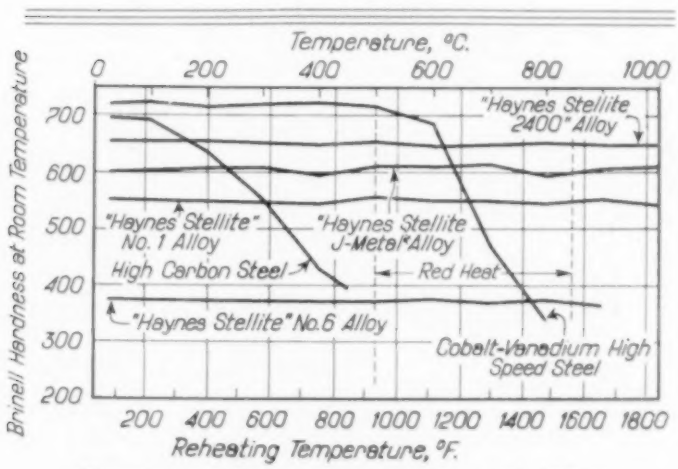
Red Hardness and Wear Resistance

Like all other metals, these alloys soften when heated, but so slowly that at temperatures above 1100° F. the grades used for tools are harder than any steel. The first graph shows the hardness of steel and cobalt-chromium-tungsten alloys. Samples of each were held for at least 30 min. at the temperature indicated. The hardness of high carbon steel is seen to drop off rapidly above 400° F.; on the other hand, the best high speed steels retain their hardness to about 950° F. The various "Haynes Stellite" alloys all retain a higher hardness above 1100° F. than high speed steel, and most of them possess considerable hardness even at a cherry red heat (1500° F.). The alloys chosen are those which are now standard in manufacture, namely "J-metal" and "2400" alloy for cutting tools, and "Haynes Stellite" No. 1, 12, and 6 for hard facing rod. Most special castings are now made from "J-metal" alloy, while forged products are made from Stellite No. 6. Approximate compositions of the three hard facing rod alloys are:

	Cobalt	Chromium	Tungsten
No. 1	>43%	<34%	<14%
No. 12	>47	<34	<10
No. 6	>55	<33	< 6

The hardness of the alloys is such that most grades are not workable and must be cast to shape and ground. The softer grades can be forged or rolled when kept at about 2100° F., but even then they can be reduced only with difficulty and in small steps. For instance the usual reduction by rolling does not exceed 0.025 in. per pass and is frequently less.

When samples of these alloys are allowed to cool, they recover practically all of their original hardness. The curves of recovery hardness are shown in the second graph, and represent the Brinell hardness of the indicated alloy measured at room temperature after a 30-min. heating at the indicated heat. No permanent loss of hardness is shown for the four stellites. The samples of high speed steel heated to 950° F. or less recovered almost completely, while those heated to 1100° F. and over were permanently soft and would have to be quenched a second time to restore their original properties. The cobalt-chromium-tungsten alloys, however, are not softened by heat treatment, and they recover their original hardness after being heated to any temperature up to at least 1850° F.



Hardness at Room Temperatures of Alloys After 30 Min. at Heat and Slow Cooling.

Cobalt for Permanent Hardness

The reason why the use of cobalt instead of iron results in permanence of hardness is not thoroughly understood, but cobalt alone has the ability to confer this property and in this respect is far different from nickel, which from a chemical point of view is considered to be a very similar element.

Another property resulting from red hardness is great wear resistance. A large number of parts such as plowshares, excavating equipment, tractor treads, dies, hot shear blades, and other parts of machinery are hard faced with Co-Cr-W alloys, after which they outlast hard steel, usually from 3 to 10 times.

Knives, punches, shears, billet scrapers, and other tools for cutting hot metal represent

another type of operation in which both wear resistance and red hardness are needed. Valves for high pressure steam service, for oil refineries, and for diesel and automotive engines have a much longer life when faced with these alloys. It is usually impossible to make the entire article or part of stellite, but the active surface can readily be covered by the hard facing process, using either oxy-acetylene or metal-arc welding, whichever is more suitable for the particular job. When properly done, the composite piece has all the wear resistant properties of these alloys where they are needed, combined with a cheap, machinable, and tough body.

As would be expected from their retention of hardness, these alloys also retain their strength at high temperatures, being decidedly strong when hot as compared to other metals. Data on this important property are shown for two alloys in the third graph, page 136.

Metallurgical Aspects

Metallurgically, the Co-Cr-W alloys consist of complex chromium and tungsten carbides in a solid solution matrix containing principally cobalt. The photomicrographs at 100 diameters shown in the data sheet, page 163, will give some indication of the type of structure encountered. The polished specimens were all etched with Murakami's reagent, and in the views marked with a star this was followed by a second etch with a mixture of hydrofluoric and nitric acids, the effect of which is to change the color of the carbide crystals from dark to light.

The structure of both metal-arc and oxy-acetylene welded alloys No. 1, 6, and 12 is shown, since welded deposits are the most common form in which these alloys are used. The metal-arc welded specimens generally show dendrites of the cobalt-rich solid solution, surrounded by a fine-grain mixture of eutectic carbides. The structure of oxy-acetylene welded alloy No. 1, shows large needle-like primary carbides in addition to the solid solution and the fine eutectic carbides; this structure is also obtained in metal-arc welded deposits if they are remelted with the oxy-acetylene flame and allowed to cool in air. Oxy-acetylene welded alloy No. 6 reveals the eutectic carbides, but it will be observed that no needles of primary carbide are present. No primary carbides are

Physical and Mechanical Properties of Standard Cobalt-Chromium-Tungsten Alloys

Property	Alloy No. 1	Alloy No. 6		Alloy No. 12	J-Metal
		Cast	Forged		
Specific gravity; Grams per cu.cm.	8.59	8.38	....	8.40	8.76
Pounds per cu.in.	0.315	0.303	....	0.303	0.316
Melting point, ° F.	2,282	2,327	....	2,306	2,318
° C.	1,250	1,275	....	1,263	1,270
Thermal conductivity					
B.t.u. per sq.ft. per in. per hr., per ° F.		102.7	....		
Calories per sq.cm. per cm. per sec., per ° C.		0.0354	....		
Specific heat, calories per ° C.	0.0938	0.1010	....	0.0978	0.0925
Mean coefficient of thermal expansion,					
Per °F. (32 to 1800° F.)	0.0000080	0.0000094	....	0.0000088	0.0000081
Per °C. (0 to 1000° C.)	0.0000144	0.0000169	....	0.0000158	0.0000146
Electrical conductivity *(a)*	1.5%	1.75%	....	1.6%	1.5%
Resistivity, ohm per cu.cm.	0.000104	0.000091	....	0.000098	0.000106
Coefficient of friction; Polished surfaces			0.11 to 0.13		
Ground surfaces			0.13 to 0.15		
Magnetic permeability			less than 1.2		
Reflecting power			68 to 83%		
Ultimate tensile strength, psi.	47,000	105,000	130,000	76,000	65,000
Elongation in 2 in.	0	1%	2%	0	0
Rockwell hardness; Oxy-acetylene welded	C-54	C-40		C-48	
Arc welded	C-45	C-31			
Cast					C-61
Transverse tests *(b)*; Ultimate load, lb.		6,100	7,050	4,470	
Deflection, in.		0.370	0.395	0.170	
Yield point, lb.		3,200	3,600	3,600	
Deflection, in.		0.105	0.125	0.124	
Modulus of elasticity, psi.	34,950,000	30,400,000			35,350,000
Compressive strength, psi.	256,000 *(c)*	220,000 *(d)*	259,000 *(d)*	193,000 *(d)*	

(a) Compared to copper at 70° F. *(b)* ¾-in. square bars on 10-in. span. *(c)* No bend. *(d)* Slight bend.

present in the structure of oxy-acetylene welded alloy No. 12, but the eutectic carbides are much coarser than in the case of the same alloy when arc welded.

The structure of the J-metal casting, taken from a ½-in. square tool bit, shows that the hard primary carbides are much more abundant in this alloy than in any of the welding rod grades. The solid solution surrounded by the eutectics gives coherence to the ground-mass of this alloy. The structure of "Haynes Stellite 2400" alloy, a recently developed and patented variety, taken from a ½-in. square tool bit, also contains primary carbides, but they are not so needle-like as in J-metal.

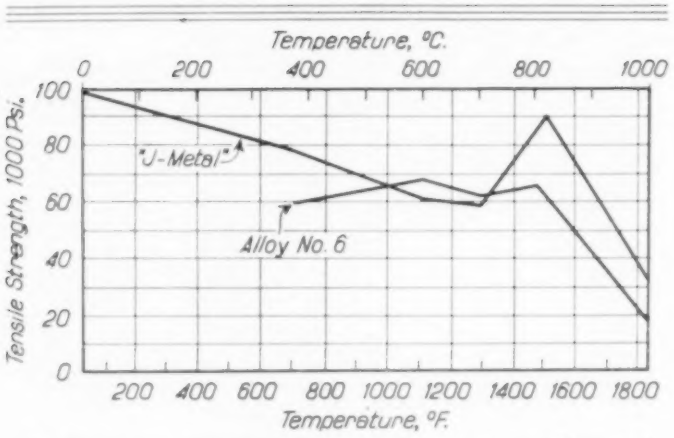
In general, the harder alloys, when viewed in the as-welded or as-cast condition, are somewhat similar in structure and contain permanent carbide crystals in a matrix consisting of at least two constituents. The softer grades are free from carbide needles and consist very largely of solid solutions containing fine eutectic carbides.

The structure of an oxy-acetylene deposit of any of the welding rod grades is similar to the original metal.

The unique structures of the harder grades, as deposited by the metal-arc process, are probably caused by the fact that the metal is heated to a very high temperature by the arc and then allowed to cool relatively quickly. The composition of the deposit has not been changed, however, and, as mentioned above, the deposit will return to its normal structure if it is remelted with the flame or in a crucible.

While different microstructures can be obtained by different welding techniques, each structure is permanent after it has been formed. Prolonged heating or reheating, accompanied by either slow or rapid cooling, does not coarsen the structure of any of the alloys, and it is impossible to pass from one of the structures to another unless the alloy is heated to its pasty stage — within a few degrees of its melting point — or completely remelted.

The effect of rolling stellite No. 6 is to elongate the eutectic patches and to give a striated appearance to the metal. The grains



Short Time Tests of Tensile Strength at Elevated Temperature of Two Co-Cr-W Alloys Suitable for Structural, Equipment and Machine Parts

are extremely fine and difficult to discern but can be seen in the light areas in the last view in the data sheet.

Properties Versus Composition

A rather unusual property found in the cobalt-chromium-tungsten system, unlike that found in copper, iron or most alloys, is that alloys in the same alloy system possessing higher tensile strengths at the same time have lower hardness. The decreased hardness is generally due to a smaller amount of tungsten and carbon in certain members. While it does not follow that the tungsten should also lower the tensile strength of the alloy, this is what is found. As a result, alloy No. 6, which contains very little tungsten, has a tensile strength in excess of 100,000 psi., and alloy No. 1, which has considerably greater hardness than No. 6, and contains a greater proportion of tungsten, has a tensile strength of but 47,000 psi. (both measured in the usual way at room temperature).

If nickel is used to replace some of the cobalt, it has a definite softening effect. Sometimes small amounts of iron, nickel, and other metals are present either as impurities coming from commercial raw materials or added for some specific effect.

If the tungsten and carbon contents are increased to over 80 and 4% respectively, with the remainder cobalt (no chromium present), the product becomes extremely hard. Such compositions are prepared by melting and casting, and are called diamond substitutes, because they take the place of industrial diamonds in certain types of work, such as oil well drilling. Small pieces of such cast tungsten carbide are welded into the cutting and reaming edges of rotary drilling or coring tools, and on the wearing surfaces of such articles as airplane tail skids, power shovel dipper teeth, and other appliances. Crushed cast tungsten carbide, made in the same manner and held in a strong steel binder, is then welded over the surface to protect the steel which supports the inserts. The excellent wear-resistance of these alloys gives the article an increased life and greater efficiency than was ever before possible.

The principal physical properties of the cobalt-chromium-tungsten alloys are given in

Laboratory Tests on Corrosion

(Concentrations expressed by weight per cent; penetration by inches per month)

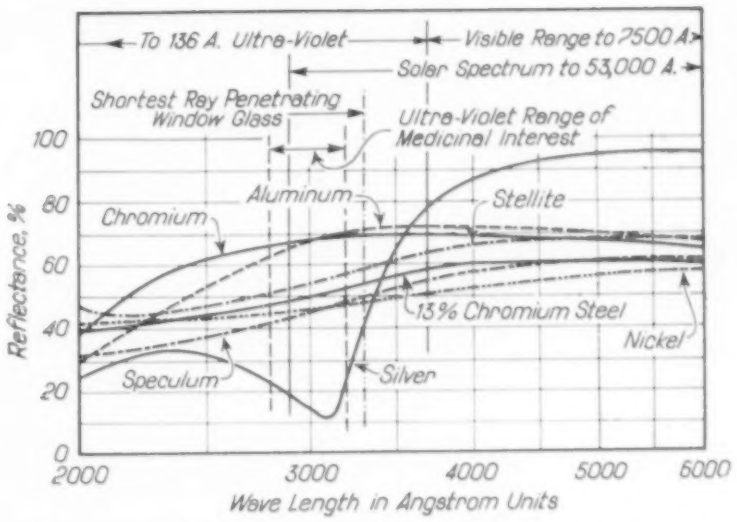
Reagent	Concentration	Temperature	Alloy No. 1 Cast	Alloy No. 6 Forged
Wet chlorine gas	Saturated	Room	+ *(b)*	0.026 *(b)*
Sulphuric acid	10%	Room	+	0.000034
	10%	Boiling	0.019	0.541
	77%	Boiling	0.102	*(a)*
Nitric acid	10%	Boiling	0.0003	+
	Concentrated	Boiling	0.022	0.172
Hydrochloric acid	10%	Room	0.002	0.018
	10%	Boiling	0.287	0.176
	Concentrated	Boiling	0.036	24.0
Phosphoric acid	30%	Boiling	0.0017	0.00014
Acetic acid	10%	Boiling	+	0.00024
	Concentrated	Boiling	+	0.0003
Ferric chloride	10%	Room	+	0.0095
	10%	Boiling	0.0063	0.172
	30%	Room	+	0.051
	30%	Boiling	0.100	0.575
Cupric chloride	10%	Room	+	0.0081
	10%	Boiling	0.069	0.243
	30%	Room	+	0.032
	30%	Boiling	0.106	0.777
Ferric sulphate	10%	Room	+	0.00010
	10%	Boiling	+	0.00017
Sodium hydroxide	30%	Boiling	0.0010	0.0037
Potassium bichromate	20%	Boiling	+	0.00017

+ No measurable penetration. *(a)* Sample destroyed. *(b)* Sample suspended in sealed bottle through which chlorine gas was constantly bubbling.

the large table on page 135. Attention is drawn to a number of special conditions regarding the values. No yield points are given, because these alloys, especially in the harder grades, have practically no ductility. In general, the elastic limits of all the alloys of the system lie very close to their ultimate strengths. Elongation rarely exceeds 2% and the reduction of area is too small to be measured.

The thermal expansion of the welding rod grades is important to assure the soundness of hard-faced surfaces. Curves showing the linear expansion of the alloys against temperature show no indications of irregularities or critical points. A reasonably good agreement in the total expansion of steel and of these alloys permits hard facing without an undue tendency toward the formation of shrinkage cracks. When hard facing the stainless alloys of chromium and iron (without nickel) it is necessary to preheat carefully and cool the hard-faced part in such a way that the final hardness is as low as possible, but with these precautions excellent results are being obtained.

An accompanying table shows the thermal expansion of stellite No. 6, the alloy used principally for facing parts which operate at high temperatures — most widely for seating surfaces on steam valves and for exhaust valves and valve seat inserts of internal combustion engines. As noted, the figures in the table for thermal expansion per deg. F. should be multiplied by one ten-millionth; that is, the expansion of a one-inch bar of alloy No. 6 per ° F. from zero to 800° F., which is indicated on the table as 81, should be written 0.0000081. Total expansion for a 2.73-in. diameter from zero to 775° F. would then be 0.0000081 × 2.73 × 775 = 0.0171 in. To convert to the coefficient of expansion per ° C., the tabular figures should be multiplied by 9/5.



Reflectivity of Various Metals Used for Mirrors at Violet and Ultra-Violet End of Spectrum. (Journal *of the Optical Society of America, vol. 19, 1929, and U. S. Bureau of Standards, Scientific Papers, vol. 342, 1919)*

Another property, which is of great importance to bearing metals, especially where lubrication is unreliable, is the coefficient of friction of the alloys. For well polished surfaces it may be as low as 0.11 (tangent of the angle of repose) and for machine ground surfaces it ranges from 0.13 to 0.15, which is low compared to that of other common metals.

It is interesting to note that when one wearing surface is hard faced with these alloys, the life of the contacting wearing surface is also increased. This is believed to be due to the fact that the alloys are so hard they do not pick up dirt or grit that would cut away the other surface, and that, because of the alloy's lower coefficient of friction, less localized heat is developed at the surfaces which are in contact.

The extreme smoothness of polished cobalt-chromium-tungsten alloy surfaces is also of advantage in the burnishing of other metals, as in the manufacture of band instruments of brass, silver, and gold. Stellite rollers for burnishing steel railroad car axle journals, locomotive crank pins, and similar parts have also proved extremely successful and have been found to be free from the *(Cont. on page 180)*

Coefficient of Thermal Expansion of Haynes Stellite No. 6 (× 10⁻⁷)
(Ranges given are in Fahrenheit temperature)

Between / and	200	400	600	800	1000	1200	1400	1600	1800
Zero	80	80	80	81	83	85	87	90	94
200		80	80	82	84	86	88	91	96
400			80	83	85	87	90	93	98
600				85	87	90	92	96	102
800					90	92	95	99	105
1000						95	97	102	107
1200							100	105	113
1400								110	120
1600									130

BIOGRAPHICAL NOTES OF EMINENT METALLURGISTS

Edward Payson Mathewson

AN APPRECIATION BY WILLIAM WRAITH

IN 1902, with the completion of the first units of Washoe Reduction Works at Anaconda, Mont., a new era in the metallurgy of copper began. Prior to that time, copper concentrators and smelters were relatively small affairs, usually located close to the mine, with daily capacities measured by hundreds of tons of ore. The Washoe plant of the Amalgamated Copper Co. (which replaced three old and small reduction works built by Marcus Daly at Anaconda to smelt ores from Butte, 30 miles away) was a large integrated unit, built on an entirely new and advantageous site, with an unheard-of capacity of 10,000 tons daily, and served by its own modern railroad. An era of expansion in demand for copper was at hand, which called for continuous expansion of plant capacity and improvements in equipment and methods. In the literature of the art between 1900 and 1920 the name of EDWARD PAYSON MATHEWSON is most frequently mentioned as the great contributor to the major improvements necessary to meet these totally new requirements.

EDWARD PAYSON MATHEWSON was born in Montreal, Canada, on October 16, 1864. He received his academic training at McGill University, graduating with the degree of B.S. in 1885. He was awarded the honorary degree of Doctor of Science from Colorado School of Mines in 1920 and Doctor of Laws from McGill University in 1922. His metallurgical career started in Pueblo, Colo., as did many another of his pioneering contemporaries; at the Pueblo Smelting Co. he served as assayer from 1886 to 1889, and as plant superintendent from 1889 to 1897. During that time the merging of many widely scattered smelting plants into the American Smelting and Refining Co. by the Guggenheim family was in progress, and in 1897 MATHEWSON joined the technical staff of Guggenheim Sons, and as superintendent and manager of their plants at Perth Amboy, N. J., Monterey, Mexico, and Antofagasta, Chile, served in that capacity until 1902 when he entered the employ of the Amalgamated Copper Co. at its brand new Washoe Reduction Works at Anaconda. In 1903 he became manager of the plant and continued as such until 1916 for the Anaconda Copper Mining Co., its then owner.

As already indicated, the Washoe Reduction Works was the wonder of the metallurgical world. It was designed and erected by FRANK KLEPETKO and CHARLES H. REPATH, who as relatively young men had come from the Michigan copper country ten years before to Great Falls, Mont., to build and operate the concentrator and smelter of Boston and Montana Consolidated Mining and Smelting Co., which in the 1890's had the distinction of being the world's largest. Yet the Washoe plant was to dwarf them all! Naturally, its design called for radical departures in size of concentration and smelting units which were to result in great increases in the productive capacity of the owning company.

The starting of such a plant also required metallurgical knowledge and experience of a high degree, and in this MATHEWSON showed his ability both as a metallurgist and as an executive. The good results obtained by the increase from the 25-ft. length of reverberatory furnaces of prior date to the 50-ft. furnaces first installed at the Washoe plant led to the idea of still further increasing the size of the units, particularly in view of the fact that the capacity of the concentrator was continually increasing. Under MATHEWSON's direction the hearth dimensions of these furnaces were increased, in steps, from 19x50 ft. to 23x134 ft. Remember that up to 1914 these were coal fired, heated from a firebox at one end; powdered fuel and natural gas were not yet installed or available at Anaconda.

Prior to the advent of concentration by flotation of copper-iron sulphides, the economics were in favor of the direct blast furnace smelting of ores containing more than 4% copper rather than the alternative plan of gravity concentration and subsequent roasting and reverberatory smelting of the concentrates. The Washoe plant, as designed, had seven 56 in. by 15 ft. blast furnaces (inside dimensions at the tuyeres). A large accumulation of blast furnace ores combined with a good copper market raised the question of increasing the capacity of this department. To add additional furnaces would require too much time, and the site and layout were rather unfavorable, so the idea was advanced that two adjacent furnaces (which were lined up in a long building, end to end) could be connected to form one furnace. The economic success of such a venture rested on the ability to remove any damaged blast furnace

jacket and replace the same while the furnace was in operation. This, successfully accomplished by a technique that enabled the operators to build up a thick crust of frozen charge, and later melt it down again, at will, led to the revision of the furnace department to contain three large smelting units, two of which were 51 ft. in length and the other 87 ft.! Metallurgists coming from all over the world were interested spectators in the repairs of these large units, where one section of a furnace would be completely shut down and the balance kept in operation.

These changes in furnace capacity led to increases in converter capacity and the introduction of many other economical features in operation. For all these MATHEWSON receives the admiration of the metallurgical world. He has been awarded the gold medals of the Institute of Mining and Metallurgy (London) in 1911, and the Mining and Metallurgical Society of America in 1917.

From 1913 to 1916 his duties were extended to include the construction and management of the International Smelting & Refining Co. (subsidiary of the Anaconda Copper Mining Co.) plants at Tooele, Utah, and East Chicago, Ind. He was general manager of the British America Nickel Corp., at Toronto from 1916 to 1918; director and consulting metallurgist of the American Smelting & Refining Co. in New York from 1918 to 1919, and consulting metallurgist since then. He has been professor of administration of mineral industries at the University of Arizona in Tucson from 1926 to date. In 1923 he was president of the American Institute of Mining and Metallurgical Engineers.

MATHEWSON has an attractive personality, most genial, and finds no task too burdensome if it will help his associates. Countless young engineers have been inspired and aided by "E.P.'s" counsel and interest, and these young men are now important factors in the copper industry all over the world. His activities cover a large field not only professionally but in civic matters as well. Any call on MATHEWSON for assistance in anything for public good, be it good roads, civic matters or the advancement of state institutions finds a ready response, and always has.

FATIGUE IN RIVETED AND WELDED STEEL

BY B. P. HAIGH AND T. S. ROBERTSON

Abstracted from a paper before the British Institution of Naval Architects, June, 1939

DETERMINATIONS of the fatigue resistance of ship plate and joints therein, either new or in various stages of corrosion after long use, have been made over a period of 25 years. From the large mass of data now made available the effect of corrosion and sea water on the endurance of plate cut from the bottom of a 20-year old ship may be quoted. Its tensile strength, on a turned test piece, was 74,000 psi. and its yield strength 51,000 psi. Endurance limit of a smooth test piece, dry, was found to be ± 33,000 and that of a piece with pitted surfaces though still serviceable was ± 22,500 psi., a figure reduced to ± 8000 psi. when the sample was moistened with sea water.

Single pairs of rivets were tested in double butt straps, thus obtaining optimum fatigue strength under ideal conditions. Values computed for typical joints on the assumption that each rivet takes its fair share of the load and without deducting the cross-section of the rivet holes are doubtless too high, but nevertheless give data with which to compare the fatigue strength of original plate and of welded joints. The limiting alternating strength for typical riveted joints with two rows of rivets under these conditions is ± 7000 psi. (that is, 7000 psi. compression to 7000 psi. tension). The customary proportions for rivets appear to be well chosen for fatigue strength. Joints so made generally broke across plate sections between the rivet holes, while the smaller diameters of rivets led to fractures by bending in such a manner that cracks developed in the rivets.

Welded joints, tested whole in large electromagnetic machines at 3000 cycles per min., gave considerable variation in fatigue strength even though companion samples were relatively constant in tensile strength. However, when the joints are produced in comparable ways, within the limits tolerated in practice, the fatigue strength can be relied upon to lie within narrower limits. In ordinary structural butt *(Continued on page 174)*

Using the popular presentation techniques of radio and the open forum, a technical discussion was conducted at the Houston meeting of International Acetylene Association in March on various phases of the problems involved in producing hard surfaces on steel. The chairman was Augustus B. Kinzel, chief metallurgist, Union Carbide and Carbon Research Laboratories, and his collaborators were John J. Crowe, research engineer of Air Reduction Sales Co., Ernest E. Thum, editor of METAL PROGRESS, *and Charles E. MacQuigg, dean of engineering, Ohio State University. The following is a synthesis of the views offered.*

SURFACE HARDENING AND HARD SURFACING

CHAIRMAN Kinzel opened the forum by noting that the properties of hardness and wear resistance were frequently regarded as the same thing, and his collaborators agreed that, in metals, hardness is one of the most important factors in resisting wear. However, there are different methods of determining hardness — such as the indentation and scratch methods, and the rebound of a tiny hammer-head which is really a measurement of elasticity — and each measures hardness in different terms. Moreover, no one set of hardness scales now in use can be employed to compare accurately the relative hardness of any two materials having widely different elastic properties.

An illustration of the error in the supposition that hardness indicates wear resistance can be made with 12% cast manganese steel, which is "soft" when measured by usual indentation methods but which becomes "hard" when cold worked. High carbon steel will outwear the manganese steel in such light service as digging soft earth or loam. Yet working in heavy gravel or rock, where impacts are severe, the manganese steel will outwear high carbon steel. Rubber, as another illustration, will outwear steel in certain classes of service.

However, it was concluded that, other things being equal, the greater the hardness the greater usually is the wear resistance of metal.

Ductility is also an important factor in resisting wear, although seldom specifically mentioned. An illustration of its importance is shown by the frequent failure of extremely hard materials which lack this quality to be suitable as wear resisting surfaces. A certain ill-defined amount of ductility is needed, depending upon the application; there is a lower limit to the necessary toughness for each application, below which spalling, chipping and undue wear occur.

Another factor of wear resistance, often of importance, is the resistance of the material to *corrosion*. Corrosion itself may not wear the material. However, should a steel shafting become pitted by corrosion, gritty material can accumulate in the pits and thereby ruin the bearing. Frequently corrosion forms a film over the material. This film may be such that it is removed as fast as it is formed. So the limiting factor here would be the rate of formation of the corrosive film. High chromium steels, and non-ferrous materials as well, might wear better at a given hardness level simply because of their resistance to corrosion.

In some cases *resistance to tempering* may be a desirable characteristic for wear resistance. In a good many wear applications, in fact in all applications where lubrication may temporarily be inadequate, the part may heat locally

to temperatures well above the boiling point of water. It is the prevailing opinion that wear, even when a coolant is used on the wearing surface, raises points on the surface to a very high instantaneous temperature. This seems to be proven by experiments wherein surface measurements were made with a sliding type of thermocouple followed by micro-examinations of the surface; the immediate surface has evidently come up to a fairly high temperature. Materials that have been quenched and that depend on this quenched condition to retain hardness, become softer as a result of this surface temperature, and their wear resistance is correspondingly reduced.

Among the steels which do not get their hardness by quenching and which resist tempering are the nitrided steels which obtain their hardness during treatments at temperatures around 900° F. These nitrided steels will hold hardness up to that temperature. Beyond this, these steels lose much of their hardness, and have to be re-nitrided to regain it.

Red hardness may be defined as the ability of a metal or an alloy to remain hard while at a "red heat", which denotes a range of temperature from about 925 to 1550° F. Of the four groups of hard surfacing materials — the low alloy steels, the high alloy steels, the non-ferrous alloys, and the tungsten carbides — the first possesses no red hardness; the second has high hardness only if alloyed sufficiently with tungsten or molybdenum; while the last two groups do possess red hardness.

Red hardness obviously is desirable in hard surfacing materials because it enables the steel to resist softening due to the generation of high heat by friction, or from particle to particle contact when the lubrication film is penetrated. It was the consensus that in many applications the temperature of particles at the point of wear does actually rise until the point is red hot, and it is necessary to have a considerable degree of surface hardness at that temperature in order to have sufficient wear resistance.

The whole subject of wear testing is in a rather unsatisfactory state. Laboratory tests give data regarding certain factors, but it is always difficult to know how much weight to give any such factors with respect to any given service. Accordingly, the whole trend of preliminary investigation is to devise a wear test that duplicates service conditions as closely as possible. One illustration of this may be found in the testing of gears for automotive service. While laboratory tests on a single tooth or on a single gear give a certain type of information, the only tests found satisfactory by industry involve operating several complete axle and gear assemblies under conditions closely approximating severe normal service.

Thus, while wear testing is useful and much may be learned therefrom, those engaged in wear testing are fully aware of the difficulty of interpreting the results of such tests.

Passing now to the problem of metals to resist wear, it was remarked that wear is a surface problem and there are several ways of producing hard, wear resisting surfaces, all of which could be termed "surface hardening". (The above attitude was qualified with the thought that the actual surface had to be held up to its duty by metal that is strong enough to carry the load, and ductile enough to absorb shocks and "give" slightly under highly concentrated loads.) While it is nearly always possible to make a complete article of wear resisting materials, the latter are likely to be expensive and lacking in toughness, so the usual preferred method is to produce a wear resisting *surface* in some way.

As is well known, the most widely used plan is to carburize the outer layer of tough steel parts by heating them in carbonaceous gases, and then hardening the surface by heat treatment. This is best adapted to comparatively small parts. Limitations due to expense hamper other methods of surface hardening by cementation and chemical reaction, such as surface impregnation with chromium or nitrogen. Often it is fairly convenient and economical to weld hard materials on softer parts with flame or arc — the process now so widely known as "hard surfacing". Finally it is possible to harden the surface of sizable pieces of steel, alloy steel and cast iron by heating the surface rapidly with an appropriate oxy-acetylene flame, and cooling it either by a water spray or merely by self-quenching. This process is known as "flame hardening".

Flame Hardening

The depth of the hardened case can and should be controlled in flame hardening, with the depth usually varying between ¼ in. and $\frac{5}{16}$ in. depending on the material's application. In the spinning method almost any depth of case can be obtained. It is not unusual to harden a 3-in. bar all the way through, where-

upon the hardness surface to center would vary in the same way as though the steel were furnace heated; it would depend on the type of steel used, the coarser-grained carbon steel or the alloy steels hardening more deeply than the finer-grained carbon steel or plain carbon steel, especially in large masses.

In hardening thin material, the depth must naturally be limited, for if it were hardened all the way through, ductility would be lacking in the backing up material.

There is no difference in stiffness between two steels having a different hardness. This is illustrated by two cantilever beams, one made of low carbon steel, the other of high carbon steel hardened to glass hardness. Both, given the same load, will bend the same amount within the elastic limit. This is because the modulus of elasticity for all steels is the same and explains why a hardened case distributes the load to the soft core. If it were possible to substitute a material of lower modulus of elasticity, such as babbitt metal, for the soft steel core, the case would take most of the load.

In the control of the flame hardening process for varying case depths, there are a number of variables, chief of which are:

1. Speed of flame head.
2. Distance of flame from piece.
3. Amount of gases which can be burned in flame head tip.
4. Distance of water quench behind flame head.
5. Pressure of quenching water.

None of these variables is critical any more than the depth of case is critical. If, for instance, a depth of ¼ in. is desired, it does not make much difference for most applications if a depth of $\frac{3}{16}$ in. or $\frac{5}{16}$ in. is obtained.

Practically the same factors determine the choice of steels for flame hardening as for furnace hardening. Each hardening process is a matter of putting heat into the steel and extracting it at the proper rate. The results depend on the steel merely to the extent of the functioning of its carbon and alloy content which control hardness, depth of hardness, and toughness of the piece.

Generally, of course, parts having complicated shape can be better hardened with flame hardening because by this method the steel is heated only locally. Also large masses of metal can best be surface hardened by flame hardening, since not only is there the quenching action of the coolant, but also the quenching effect in the other direction of a large cold mass of metal underneath.

It would be difficult or even impossible to estimate the internal stresses set up by the quench hardening process, either after a soaking heat in a furnace, or after a brief sharp heat under an oxy-acetylene flame. In a general way, the men contributing to the discussion agreed that the internal stresses in a properly flame hardened piece of steel are likely to be less than those found in a furnace hardened piece. The reason for this is that in flame hardening, a small band or relatively thin surface is heated above its transformation range and is hardened. It is backed up by the colder part that does not go through the transformation. In furnace hardening, however, the whole piece is heated above the critical temperature, and in rapid cooling the whole piece goes through the transformation progressively, producing an expansion and contraction in different parts of the piece at different times.

It is of course possible to relieve some of these stresses by a prompt tempering at a temperature low enough to avoid any loss in hardness. Although the practice of stress relieving dates at least as far back as 1620, the theory and mechanism are not yet fully understood. The general opinion, however, is that when a quenched steel is reheated to about 400° F., the interrupted transformations have a chance to complete themselves, at least partially. There is a little atomic motion along with the molecu-

Surface Hardening a Large Shaft by Spinning it Within a Circle of Slowly Advancing Flames, With Quenching Jets Just Behind. Photo courtesy of High Speed Alloys, Ltd.

lar movement at this low temperature and this relieves the stresses by internal movements similar to plastic flow in the metal.

Since most surfaces which resist wear must also resist alternating or widely fluctuating loads, the question of fatigue resistance or endurance limit of flame hardened surfaces is worthy of some consideration. Endurance limit of steel generally improves in direct ratio to the ultimate strength, and tensile strength is also proportional to the hardness. Now in flame hardening, the tensile strength at the surface is increased. Since the maximum stresses usually occur at the surface, it can be said that flame hardening increases the fatigue strength of the piece. For increasing the fatigue strength of such pieces as the heavier gears, where there are heavy unit pressures, the hardened case may be carried to a greater depth.

Hard Surfacing

Hard surfacing, or the welding on of wear resisting substances, is also well known and widely practiced. As previously mentioned four general classes of materials may be used:

1. Plain carbon or low alloy steels, typified by high carbon, medium manganese steel.
2. High alloy steels, typified by high chromium and nickel-chromium stainless steels.
3. Non-ferrous alloys, typified by cobalt-chromium-tungsten alloys.
4. Tungsten carbides or diamond substitutes.

Generally speaking, such layers are welded on by a technique that will leave a surface hard enough and ductile enough so that the part can be used without further heat treatment. This is especially true of hard surfacing materials that may be applied by "sweating" on the base metal at a comparatively low temperature.

However, in applying the diamond substitutes by that method wherein the base material is puddled, the effect of the heat of operation is to increase the grain size of the base material, the increase corresponding to the temperature as it goes from the melting point at the surface into the steel. In such cases, the steel can be heat treated to restore the original properties.

Mention was made of several important industrial applications of hard surfacing, such as for bits for oil well drilling. A less well known instance is in exhaust valve construction in aircraft engines, particularly those in fighters and pursuit planes. In these, the problem is as much a matter of corrosion as it is of wear, though where the hot gases pass between the bottom of the valve and the top of the valve seat there are definite aspects of wear and erosion as well as corrosion.

These aircraft valves are usually made of high alloy austenitic steel and cannot, therefore, be hardened by heat treatment. However, the underside of these valves is coated; in the United States a chromium-tungsten-cobalt alloy is used to give it resistance, while in England, the above alloy as well as an alloy containing approximately 80% nickel and 20% chromium is often used for this coating. This latter alloy is not hard in the usual sense, but because a very thin layer is used and it has excellent resistance to hot gases it has little tendency to flow under impact or be corroded chemically.

The ends of the valve stems where the tappets strike are usually welded-on nibs of ordinary high carbon steel, which are often hardened by heat treatment with a blowpipe.

Modern Fish Tail Bit by Reed Roller Bit Co. Diamond substitutes are embedded in wing cutters and edges, and concave surfaces protected by hard surfacing material welded on

In order to maintain a relative accuracy of ±20° F. in temperature readings on molten steel it is necessary for the observer to select conditions when smoke and fume are at the minimum, to observe liquid steel clear of slag and oxide patches, and have a keen eye, quick reactions and necessary training in the manipulation of the instrument. Likewise it is necessary that the pyrometer be in good working condition, both as an assemblage and in all its individual parts. The latter depends on routine weekly cleaning, inspection and calibration. Methods used in a large steel plant are as described in the article below.

MAINTENANCE OF OPTICAL PYROMETERS

BY MARY BAEYERTZ AND JOHN F. PERKINS
Metallurgical Laboratory, Carnegie-Illinois Steel Corp., Chicago

AN OPTICAL PYROMETER has many advantages as an instrument for the determination of the temperature of molten steel and of heated steel in production processes such as rolling, forging and heat treatment. Properly used, it will measure a wide range of high temperatures with good precision. It is a self contained instrument of such size and weight that it can be carried by the observer from one job to another. Moreover, it can be used at a considerable distance from the glowing body (as is necessary during the tapping and teeming of a heat of steel).

On the other side of the picture, the drawbacks of the optical pyrometer are the large emissivity correction required when used to read temperatures of molten steel in the open, the lack of continuous automatic recording and controlling features, and the personal factor involved in its use. The last mentioned can be largely eliminated by adequate training and supervision of the pyrometer readers.

In the steel mill the advantages far outweigh the drawbacks, making the optical pyrometer a very useful instrument.

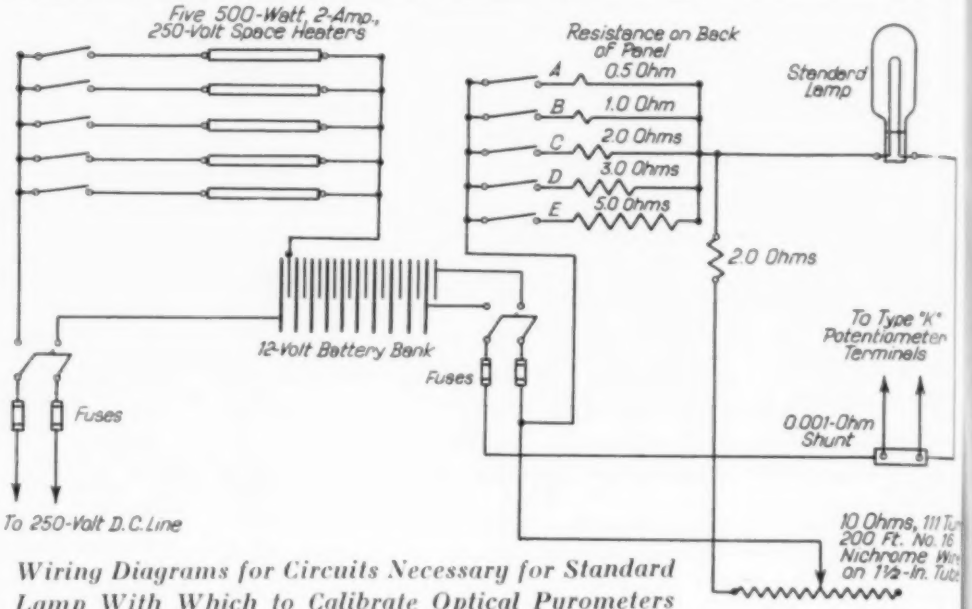
In common with other measuring instruments, the optical pyrometer will operate for a time with its original precision, until dirt, corrosion, or mechanical damage cause deviation from the calibration. Since this period may be longer or shorter depending on the instrument and the conditions of use, periodic checking is required in order to prevent the use of pyrometers with reduced precision.

At the South Works of Carnegie-Illinois Steel Corp. it has been found advisable to make the cleaning and checking of each optical pyrometer a weekly routine. A laboratory has been equipped and a trained staff is maintained for this work. The same staff can, if necessary, make adjustments and repairs and calibrate the instruments before they are returned to service.

At the present time a single make of optical pyrometer of the disappearing filament type is used almost exclusively by us, and 27 of them are now in active service. As is doubtless well known, this instrument is essentially a photometer, by which the brightness of a lamp filament is matched with the brightness of an image of the glowing object, the temperature of which is to be measured. The pyrometer consists of a telescope (which contains the lamp and suitable filters besides an optical system consisting of an objective lens, eyepiece lens and their defining diaphragms) and a box

which contains the battery and equipment for controlling and measuring the lamp current.

When making a temperature measurement an image of the glowing object is focussed in the plane of the lamp filament by the objective lens of the pyrometer telescope. Thus the pyrometer can be used either close to or far away from the glowing object. If the lens is kept properly focussed, an increase in the distance merely decreases the size of the image while the intensity remains practically constant. The glowing object must, however, be near enough so that its image is fairly large by comparison with the lamp filament.



Wiring Diagrams for Circuits Necessary for Standard Lamp With Which to Calibrate Optical Pyrometers

Intensities are matched with approximately monochromatic light of a wave length of about 0.65 micron (6500 Ångström units) which is obtained by interposing an orange filter between the eyepiece and the lamp. The use of monochromatic light makes the measurement depend entirely on the matching of brightness, which is of considerable advantage to the operator who may be color blind.

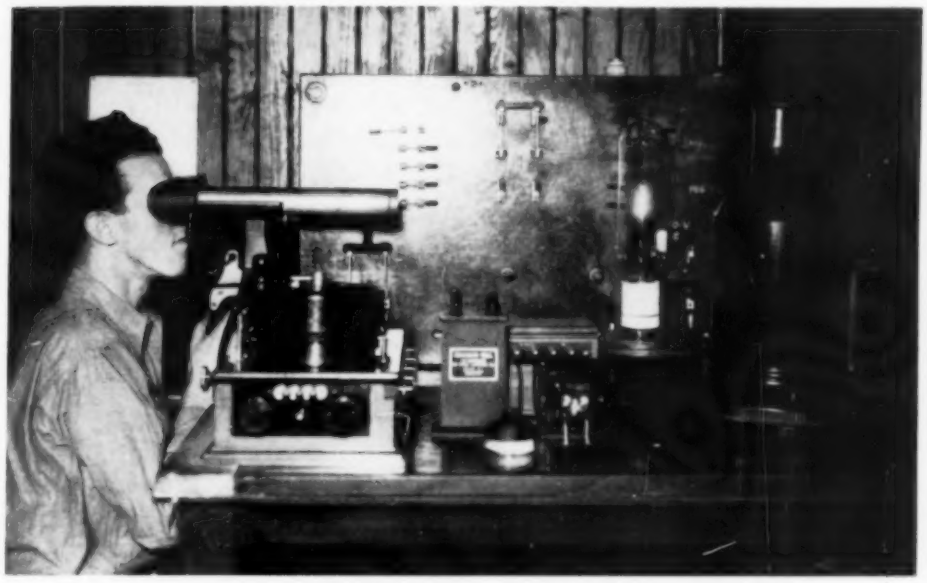
Double range instruments also have an absorbing screen, which is interposed between the pyrometer lamp and the objective lens when using the high range. This absorbing screen is of glass and should have a transmission practically unaffected by wave length, within the narrow band of wave lengths around the 0.65 micron transmitted by the monochromatic light filter. The purpose of the absorbing screen is to reduce the intensity of the light from the glowing object, in order to increase the range of temperature which can be determined without exceeding a safe working temperature for the pyrometer lamp. Thus if a visual blend is made when the absorbing screen is in place, the glowing object appears to have the same brightness as the pyrometer lamp filament, but the pyrometer lamp filament is actually at a lower temperature. Both ranges of such instruments are calibrated to read directly in temperature.

The brightness of the pyrometer lamp filament depends on the amount of current passing through the filament and is controlled by adjusting a rheostat, in series with the lamp and the dry cells which supply the lamp current. The current is read on a milliammeter, also in series in the lamp circuit. In order to measure temperatures with this instrument the readings of the milliammeter, for each particular lamp, must be calibrated in terms of temperature.

This calibration is made by comparison with a standard lamp in the laboratory. The wiring diagram of this standard lamp circuit is shown in the first drawing. Current is supplied by a 135 ampere-hour storage battery; a battery of large capacity, properly charged, insures a constant voltage in the standard lamp circuit during a reading. The circuit contains several resistances in steps from 0.5 to 2 ohms and a variable resistance of 10 ohms, which together provide the means of varying the current supplied to the standard lamp. The current in the standard lamp circuit is determined by measuring the voltage drop across a calibrated 0.001-ohm shunt, in series in the lamp circuit, with a precision potentiometer.

A photograph also shows the calibrating equipment, with the standard lamp and potentiometer in place. The lamp cover — used to shield the lamp from external light which might affect the readings — has been removed and placed at one side. The calibrated 0.001-ohm shunt stands to the right and behind the lamp cover. Resistances for controlling the lamp current are on the back of the panel on the far side of the table, and the switches for throwing them in or out of the circuit are seen. The battery is kept in its own compartment back of this equipment.

The standard lamp is of the tungsten ribbon



Bench Set up for Calibration of Optical Pyrometer. (Lamp cover has been set aside, at right of standard lamp)

filament type. The resistance of such a filament, and therefore its brightness when electrically heated, varies slightly from point to point, and hence the same spot must be sighted each time when calibrating an optical pyrometer. For this reason the standard lamp filament is provided with a notch on one side, somewhat below its curved top, and the pyrometer telescope is held in a fixture so that the curved tip of the pyrometer lamp filament covers the standard lamp filament at the notch. A mechanical support with vernier adjustments is provided for the pyrometer telescope so that it can be fixed in the proper position and then be held steadily in place while the readings are taken.

Two calibrated standard lamps are kept in the laboratory. One of these is used in the actual checking operation, while the other is held in reserve. Thus it is possible to ascertain at any time whether the standard lamp has deviated from its calibration merely by checking both lamps against the same pyrometer.

The standard lamps are calibrated at the U. S. Steel Corp. Research Laboratory by optical pyrometers which have, in turn, been calibrated by the U. S. Bureau of Standards. Calibration consists of a table of lamp currents and corresponding brightness temperatures, as shown below. The certified optical pyrometers are calibrated for black body radiation by the U. S. Bureau of Standards. Accordingly it follows that the standard lamps and, in turn, the optical pyrometers for use in the mill are likewise calibrated for black body radiation.

Typical Calibration of a Standard Lamp

Amperes	°F.	Amperes	°F.	Amperes	°F.
5.0	1554	7.5	2360	10.0	2919
5.5	1756	8.0	2482	10.5	3007
6.0	1933	8.5	2583	11.0	3103
6.5	2079	9.0	2712	11.5	3189
7.0	2228	9.5	2784	12.0	3280

An emissivity correction is applied to optical pyrometer readings when necessary. This correction is one of the most troublesome factors in the use of optical pyrometers, since glowing bodies differ in emissivity. The highest emissivity is obtained from a radiating black body, and has been given the value of unity. Slag, steel and many other radiating bodies have emissivities of considerably less than one. If the temperature of such bodies is measured in the open, so that no reflection occurs, a correction must be added to temperatures determined with an optical pyrometer calibrated for black body.

For example, in determining the tapping temperature of a heat of steel from an open-hearth furnace, the measurement is made by sighting the stream of molten steel in the open as it comes from the furnace. Under these conditions the emissivity correction for steel is large, since the temperature of the molten steel is high and the emissivity has been determined to be about 0.40 for a wave length of 0.65 micron. On the other hand the emissivities of furnace slag and iron oxide are considerably higher than that of steel. The temperature reading must therefore be taken on the darker portions of the stream (corresponding to the lower emissivity of steel not covered by a film of oxide) before the furnace slag starts to run with the steel into the ladle.

Careful consideration of the temperature measurement to be made, and instruction and training of the pyrometer observers are therefore essential. Only with these precautions can an emissivity correction be applied with any assurance of accurate conclusions.

When an optical pyrometer is brought to the laboratory for its weekly inspection, it is first checked as a unit against the standard lamp at several points on its temperature range. The resistances in the standard lamp circuit are adjusted to bring the standard lamp filament to the brightness temperature corresponding to the temperature at which it is desired to check the optical pyrometer. (It will be remembered that the lamp current is determined from the e.m.f. drop across the 0.001-ohm shunt.) When heating from room temperature, the standard lamp is allowed to season two minutes at temperature, until the emission from the filament becomes essentially constant. The optical pyrometer is then sighted on the standard lamp filament at the notch, and the current in the pyrometer adjusted so that a blend is obtained.

To be considered satisfactory the reading of the pyrometer, according to its latest calibration, must coincide with that of the standard lamp within ± 10° F. over its full range. This procedure checks the pyrometer as a unified instrument and determines its precision as used previous to this check. It is then cleaned, and again compared with the standard lamp at intervals over its full range before it is returned to service.

If the pyrometer does not agree with the standard lamp within the satisfactory limit, the pyrometer's milliammeter is checked alone. This is done by cutting the lamp out of the circuit, leaving the milliammeter, rheostat and dry cells in series. A calibrated 0.1-ohm shunt is then placed in series in the circuit and the current is varied by changing the setting of the rheostat and measured at several points on the scale by determining the e.m.f. drop across the 0.1-ohm shunt with a precision potentiometer. If the readings deviate from the uniform printed scale, the milliammeter is cleaned and, if necessary, the magnetic shunts attached to the pole shoes are adjusted to correct the moving coil deflections over the scale. A milliammeter which does not deviate more than ± 1 milliampere at any reading on its scale is considered satisfactory.

Calibration for an Optical Pyrometer

Low Range		High Range	
Milli-Amperes	°F.	Milli-Amperes	°F.
330	1551	360	2175
340	1640	370	2260
350	1716	380	2343
360	1791	390	2421
370	1857	400	2493
380	1919	410	2564
390	1975	420	2633
400	2027	430	2699
410	2076	440	2762
420	2124	450	2822
430	2169	460	2881
440	2214	470	2938
450	2257	480	2995
460	2300	490	3048
470	2338	500	3101
480	2376	510	3151

If the milliammeter reads correctly and the other equipment in the pyrometer box is in good shape, the pyrometer lamp is inspected and replaced with another if thought necessary. A new calibration of the pyrometer as a unit is then made by comparing the pyrometer lamp with the standard lamp at small temperature intervals over the full range of the pyrometer. The procedure is the same as that described for checking pyrometers when first returned to the laboratory. Such a calibration is shown.

As already mentioned, when a pyrometer has been used for a week in the mill, it must again check this calibration within ± 10° F. before being returned to service. This is the limit of precision allowed under the conditions used in calibrating, but the absolute accuracy as true temperature readings of the pyrometer as taken in the mill is undoubtedly less than this. Possible errors in plant use may be divided into two groups: The first of these is the accuracy of the calibration of the standard lamp and in turn of the optical pyrometers. This depends upon the absolute accuracy of the calibration of the pyrometers certified by the U. S. Bureau of Standards and the precision with which this is transferred in calibrating the standard lamps and the optical pyrometers for use in the mill. The second group of possible errors arises from the conditions of use in the mill such as smoke or fumes between the glowing object and the pyrometer, the doubt concerning the absolute value of the emissivity correction, and the use of the optical pyrometer at temperatures differing greatly from that at which the instrument was calibrated.

Considering the method of calibration and the conditions of use, the reproducibility of temperature readings in the mill is considered to be within ± 20° F., but the absolute accuracy is undoubtedly less. Although absolute accuracy is of course the ultimate goal, measurements of relative temperatures are now precise enough for the consistent production of numerous types of steels, each of which must be satisfactory for its particular application.

At the World Automotive Engineering Congress, sponsored by the Society of Automotive Engineers in Detroit early in June, Ernest F. Davis, chief metallurgist of Warner Gear Co., presented a paper entitled "What Is New in Heat Treating Methods, Material and Process?" The article which follows is a slightly condensed version of comments made by Mr. Darrah on one phase of Mr. Davis's discussion, and in it he summarizes the principal modern methods of gas carburizing and describes a modification wherein the flame is muffled.

THREE METHODS OF GAS CARBURIZING

BY W. A. DARRAH
President, Continental Industrial Engineers, Inc., Chicago

A CLASSIFICATION of the various methods of gas carburizing now in use would show three distinct types. They are in a measure representative of divergent schools of thought, yet incidental conditions frequently control the type of basic process utilized for a specific application.

It is well known that carbon is very easily added to the surface of most steels by heating them to the required temperature in an atmosphere containing sufficient quantities of carburizing gases. In theory the process at first appears quite simple, but when the effort is made to carry it out on a large scale in production, numerous and frequently quite costly difficulties appear.

One of the worst is the formation of a coating or a scale of carbon, often quite adherent and difficult to remove from the steel. Of course, the parts can be sand blasted or otherwise cleaned, but this is costly. Therefore much effort has been directed to prevent its formation rather than go to the trouble of removing it.

Incidentally, it is well recognized that such soot does not interfere with very shallow cases of low carbon content, but when case depths of 0.070 or 0.080 in. are required, or when the carbon content in the case must be around 1.00%, the coating of scaly carbon becomes a metallurgical factor. Various problems are, of course, involved in controlling the depth and carbon content of the case and this control frequently involves a corresponding problem in producing — or avoiding — carbon scale or soot.

The various distinctive methods of carburizing are therefore based on the effort to avoid soot or carbon scale while obtaining the required depth of case and carbon content. The three outstanding methods of accomplishing this result may be denoted thus:

1. Methods designed to remove carbon scale after formation.

2. Methods designed to control the formation of soot and carbon scale.

3. Methods to prevent the formation of soot and carbon scale.

Burning the Carbon Scale

Methods designed to remove the carbon scale after its formation and before the carburized parts leave the furnace are based on the assumption that the formation of a layer of free carbon on the steel is a distinct aid in carburization. The writer's experience has pointed to a contrary assumption. However, its proponents recommend the formation of soot on the work as soon as practicable after it enters

the furnace, and then provide an atmosphere in the rest of the furnace containing oxidizing gases which will "dissolve" or burn off the carbon.

The writer's experience with this process indicates that it is next to impossible to remove a normal carbon scale (or even much soot) without either decarburizing or otherwise affecting the carbon case. In other words, the margin between a proper removal of a carbon soot and a decarburization of the case is a relatively narrow one from the standpoint of practical shop operation. It has also been definitely proven in the laboratory as well as in practice that excellent and more rapid cases may be obtained *without* the formation of free carbon on the metal at any time.

Control of Soot

The second method, designed to control the formation of soot and carbon scale, according to the writer's information, is a more recent development than the first described and is apparently designed to operate on the theory that if the carbon-forming gases are kept at a proper concentration and nature, soot and various forms of free carbon may be prevented.

This process is also in successful commercial operation, but also depends on certain marginal features which are difficult for the average shop operator to control. In it a controlled "carrier" atmosphere is circulated through the furnace, out of the furnace and back again. This "carrier" atmosphere is relatively inert, and proper additions of carburizing gases are added continually in precise amounts. These activators are mainly simple and cheap hydrocarbons such as methane or propane.

The fact that this method is operative speaks for itself but, according to the writer's experience in the laboratory and also in observing numerous installations, great and continuous care is needed to adjust correctly the amount of carburizing or activating gas added to the carrier. If an excess is added, it will be evident that the cooler mixture of circulating atmosphere and carburizing gas will come in contact with the hot steel part being carburized and will deposit on these parts a layer of carbon or soot which defeats one of the objects of the operation.

This process, therefore, according to the writer's examination, is like the first process described — operative but requires very exacting controls and involves continual vigilance. In both processes it is necessary to control the time cycle, the temperature cycle and atmosphere composition, and all of these controls must be maintained within close limits — very close.

It may also be mentioned that the cost of cleaning such parts as do acquire a sooty surface in large production frequently amounts to as much as twice the cost of carburizing them, so the importance of clean work is apparent.

Preventing Soot

Being mindful of the difficulties which appear to be inherent in the above processes, the alternative of *preventing* the formation of soot appeared to have many advantages. Particularly it would eliminate the requirement for constant vigilance on the part of the shop operators if it could be simple enough so that any non-technical men could obtain reasonably consistent results.

It was assumed that the formation of the soot, free carbon, or carbon scale was the result of bringing the carburizing gas into contact with the steel to be treated while the steel is hotter than any temperature to which the gas atmosphere as a whole had been previously subjected. According to this theory — which appears to be substantiated by practice — carbon will condense or precipitate from carbonaceous gases on

steel and certain other metals depending on the gas composition and the metal temperature.

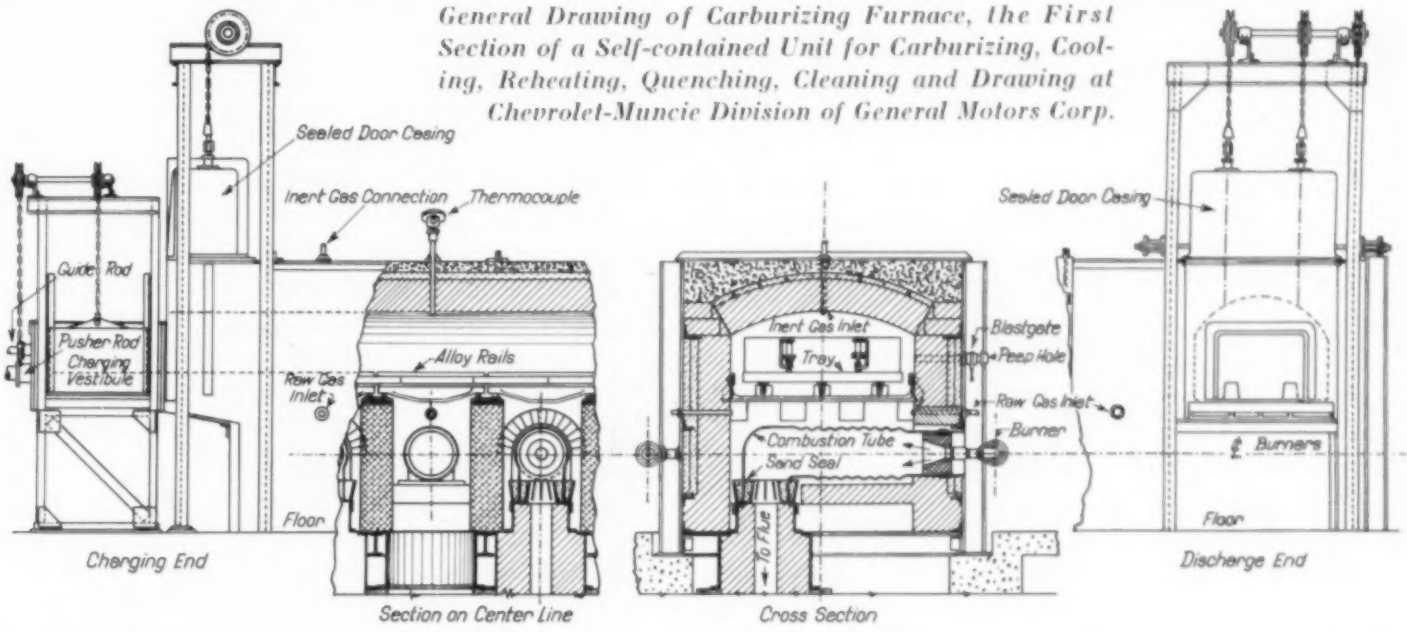
Obviously if the carburizing atmosphere has once been heated in contact with the metal or a proper catalyst, most if not all of the free or unstable carbon will be precipitated. If this gas under this stabilized condition is then brought in contact with more steel at a lower temperature no further precipitation of free carbon should take place, provided the proper time and treatment has been accorded to the atmosphere previously.

Theoretically the steel being treated would not receive precipitated carbon from an atmosphere that had been previously heated to *exactly* the same temperature as the steel. Practically this condition requires too exact a control for shop operation and fortunately there is an easy way to heat the carburizing atmosphere to a slightly higher temperature, merely by bringing it in contact with the heat resisting alloy tubes which apply heat to the furnace. The atmosphere after passing near the hot tubes will rise owing to the thermal expansion and pass over the steel being treated. This involves, therefore, a circulation of the atmosphere *within* the furnace under such conditions that the carburizing atmosphere is always somewhat warmer than the steel with which it contacts. It has been found in the operation of a large furnace in production that such an atmosphere will not precipitate carbon on steel being carburized.

Doubts that under these conditions a carburized case could be obtained in any reasonable time were answered in practice. Results rather surprisingly prove that carburization is actually speeded up by causing the gases to be hotter than the steel at the time of contact, and the ultimate carbon content and depth of case are both greater at a given time than are ordinarily obtained by the other two basic processes described above. It is possible that pre-treatment of the carburizing atmosphere converts some of the constituents into a new form, where they may be in a nascent or at least an activated state. Observations on the resultant case and conditions within the furnace indicate that some of the carbonyls (of nickel or of iron, perhaps) play an important part in this pre-treatment.

As a result of actual commercial production in a large automotive plant, in equipment described in METAL PROGRESS for December 1938, the process has proved that it can automatically and without attention on the part of an operator produce and reproduce uniform carbon cases having predetermined depth and predetermined carbon content. All of this is commercially accomplished without the production of soot or carbon scale. In addition to the data and illustrations given in the previous publication, a general drawing of the carburizing furnace may be of more than passing interest.

General Drawing of Carburizing Furnace, the First Section of a Self-contained Unit for Carburizing, Cooling, Reheating, Quenching, Cleaning and Drawing at Chevrolet-Muncie Division of General Motors Corp.



Los Angeles Chapter's March meeting was reported as unusually good, so the Editor prevailed upon Mr. McKenna to put the gist of his talk down on paper for the benefit of about 10,000 other ASMembers. His method of formulating complex carbides by dissolving their constituents in molten nickel is quite different from the ordinary process of mixing metal and carbon powders and heating them in hydrogen. Tools made of these newer carbides are also more suitable for cutting steel, a field not well served by tungsten carbides.

HARD INTERMETALLIC COMPOUNDS FOR NEW METAL CUTTING TOOLS

BY PHILIP M. McKENNA
President, McKenna Metals Co., Latrobe, Pa.

THE MAKING OF METALS or carburized metals into implements, tools, or weapons by methods of powder metallurgy (that is, without complete melting) is not new. What *is* new are the processes by which dense, strong, and hard metallic compositions are now produced, and the new forms of intermetallic compounds used as ingredients. It is unnecessary to describe here such historic examples as the production of sponge iron and its carburization without melting; the work of Wollaston over a century ago in making platinum from powder without melting; and the modern production of refractory metal wire, sheet and tube, such as those of tungsten, tantalum, molybdenum and other rare metals. These instances are well known to most readers.

Metallurgists are also well acquainted with the high hardness of carburized tungsten, reported as early as 1890 by Moissan as between sapphire and diamond, and now generally assigned a scratch test hardness on Moh's scale of 9.8, equal to that of silicon carbide or carborundum. By 1912 a use was suggested for this valuable property of high hardness, and melted globules of carburized tungsten were made into jewel bearings for meters. As a substitute for diamond dies for drawing fine wire, compositions of tungsten and cobalt were employed in Holland, and carburized tungsten was used particularly in Germany.

With this start the development of tool materials was fairly rapid. About 1919 Lohman made tool and die materials, chiefly of tungsten carbide, by processes of powder metallurgy. He crushed tungsten carbide to a fine powder, pressed it in iron dies to pieces of an accurate shape and size, and heated them to a temperature below the melting point, when he states "a recrystallization process took place", producing a more durable tool material than could be obtained by melting. C. B. Laise, in 1921 in America, produced carburized and cemented compositions consisting of tungsten, carbon, and titanium, with about 6 to 10% of nickel or iron, for use as tool edges and drawing dies. German investigators cemented tungsten carbide particles with up to 10% cobalt, producing tool and die compositions which are the basis of the modern tools for machining cast iron, non-ferrous metals, and such substances as bakelite, wood compositions, porcelain, glass and hard rubber. Much use is also made of them as drawing dies for drawing wire and rods. These materials have been manufactured by a group of concerns in America for some years under licenses from these German patentees, and are now well known in our industry as cemented

tungsten carbide alloys, or more popularly by their various trade names.

These cemented tungsten carbide compositions are excellent for machining materials of which the chips break short, because of the low tensile strength or high brittleness of the material being cut. The high thermal conductivity of cemented tungsten carbide is suitable for tool edges where the pulverulent chips localize the frictional heat within a few thousandths of an inch of the cutting edge, for the frictional heat is carried away and distributed in the whole tool more quickly. The author has measured the thermal conductivities of tool materials by a direct method described in Technical Publication No. 897 of the American Institute of Mining and Metallurgical Engineers, February 1938, and observed the value of 0.185 calories per second per degree Centigrade per centimeter for such cemented compositions of tungsten carbide with 6% cobalt. This is three times that of high speed steel, which in the quenched and drawn condition was found to be 0.061 calories.

The temperature of the cutting edge of a tungsten carbide tool, turning fine-grained cast iron at 400 ft. per min., has also been observed by the author. The work piece and the tool point were used as a thermocouple after insulating the carbide from the lathe by mica. The micro-volts generated at the contact of tool and work were interpreted by a graph obtained by plotting observed voltages for different temperatures of a thermocouple made of a piece cut from the cast iron test log and the tungsten carbide tool that did the cutting. A temperature of 1400° F. was indicated when cutting at 400 ft. per min. Strange to say, changes in feed and depth of cut had little influence on the temperature observed, this being almost entirely a function of the speed of cutting. At temperatures above 1400° F. carbide particles would "wash out" of the tip by reason of the softening of the cobalt bond.

In machining materials of comparatively low tensile strength, such as cast iron, the breaking strength of the tool edge is of little importance, and cemented tungsten carbide is sufficiently strong for most machining operations with continuous cutting. Quite another problem, however, is presented by steels and other tough alloys of higher tensile strength.

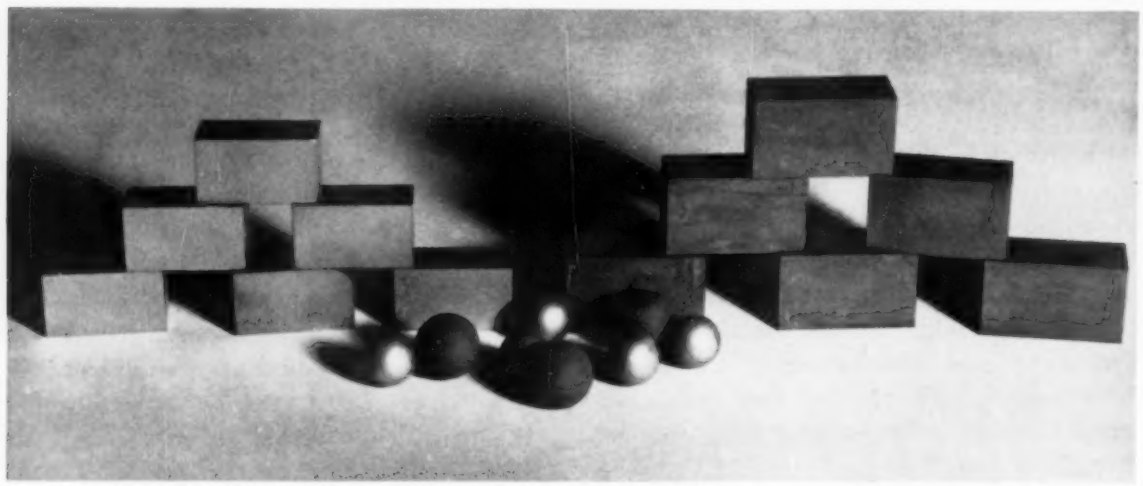
Tool wear, when machining this class of material, is of a different nature; it occurs considerably further back from the cutting edge and consists of two parts — *(a)* "cratering" due to the welding or "pick up" of particles of the tool metal to the rapidly moving steel chip and *(b)* wear down the front of the tool by the escape of particles of the steel forced down between tool and work. This excessive abrasion precluded the use of tungsten carbide cemented with cobalt for the task of machining steels.

Improved Binders

In the meantime, carburized tantalum cemented with nickel had been found to provide a tool material which machined steel without this "cratering" effect. Compositions containing tantalum carburized to about 5.75% carbon were tried, cemented with 3 to 15% of nickel as well as with 3 to 15% cobalt, but these compositions were of little commercial use, due to their low and erratic strength. Nickel as a binder gave greater strength than cobalt, but these tool compositions were soon abandoned in favor of those with a strengthened binder containing substantial amounts of metallic tungsten.

Tests made by the author indicated that the carburized metals, either tungsten or tantalum, which had been obtained by heating with carbon or a hydrocarbon gas, were not homogeneous chemical compounds. Mechanical processes, such as air separation, or "panning" with liquids, would separate fractions containing different percentages of carbon. A new form of tantalum carbide, having different physical properties than the carburized tantalum previously known, consisting of golden colored crystals with metallic luster, having an exact mon-atomic ratio of carbon to tantalum and analyzing 6.22% carbon, was obtained by a process of dissolving tantalum in molten aluminum, in the presence of carbon, and heating to about 2000° C. in graphite crucibles. The crystals were isolated by treating the cooled mass with acids, and thus removing the aluminum and aluminum carbide.

This new form of tantalum carbide had a density of 14.48 compared to the previously known form which had a density of 14.05. Its importance was that stronger steel-cutting tool materials could be made from it, having at the same time equal or greater hardness. Such compositions containing this TaC and binders of tungsten and nickel were used for steel cutting tools and had "crater" resistance, greater strength, and a thermal conductivity of about 0.07 (on the same order as that of high speed steel), as well as consistent properties.

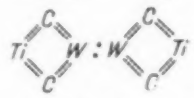


Tool Tips and Brinell Testing Balls, Before and After Sintering, Showing That Large Shrinkage (22%) Does Not Warp Flat Surfaces or Round-Off Sharp Edges

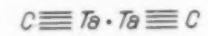
The discovery of another chemical compound corresponding to the simple formula $WTiC_2$ (or, structurally, $W_2Ti_2C_4$) has enabled us to produce a tool material for steel cutting which has an even better combination of strength and hardness. This new intermetallic compound is the basic ingredient of a series of steel cutting alloys, now to be described, and which are known as "Kennametal".

This compound is synthesized in a metallic menstruum, or bath of nickel, at a temperature above 2000° C. by heating tungsten and titanium with graphite in a graphite crucible. Only in this way was the compound formed, for the molten nickel provided a solvent in which the three component atoms, tungsten, titanium and carbon, could group themselves into this compound. The process is analogous to the formation of ammonium phospho-molybdate, familiar to chemists in the steel works laboratory in the determination of phosphorus, requiring a certain water solution of constituents, a definite concentration of nitric acid, and lengthy agitation to permit the three kinds of ions to combine. Such reactions are very slow compared to syntheses involving only two kinds of ions or atoms, for the chances of the three different atoms (in this case it is really four, for two carbon atoms are required) colliding simultaneously is much less than in a simple reaction between only two. But they *do* so combine, being all quite soluble in superheated nickel.

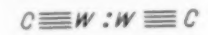
The crystalline compound $WTiC_2$ is thus formed in a nickel bath, from which it is separated, after cooling, by treating with chemical solutions such as aqua regia, and subsequent gravity separation. The compound contains 9.39% carbon as required by the formula, and has equal atomic percentages of tungsten and titanium. Structurally it may be indicated:



In this formula dashes represent ionic or polar bonds (valency electrons transferred to adjoining atoms to complete stable electron groups) and the dots covalent or homopolar bonds (electrons shared by adjoining atoms). There is an interesting thing about this structure, namely that in the compound as above represented, the ratio of homopolar bonds to total bonds is exactly the same as in tantalum carbide namely 2 to 18, or 1 to 9. Tantalum carbide, TaC or Ta_2C_2, may be represented as



and thus has one homopolar bond to nine total bonds. Tungsten carbide, WC or W_2C_2, has the following electronic bonding:



and has a ratio of homopolar to total bonds of 2 to 10 or 1 to 5.

Metallicity, or those properties associated with metals, such as electrical and thermal conductivity and metallic luster, generally vary with the ratio of homopolar bonds to total bonds — in fact, homopolar bonds are called "metallic linkages" by William Hume-Rothery, a leading English authority on atomic physics. It is not surprising, then, that tungsten carbide conducts heat approximately as the ratio of 1/5 to 1/9 or nearly twice as fast as $WTiC_2$ or

TaC, and that these latter two compounds are equal conductors compared to each other. This is verified by noting that thermal conductivities of the hard compositions of the three compounds, when cemented with equivalent volumes of the same metal such as cobalt, conduct heat in proportion to the homopolar bonds in the three compounds, and that both tantalum carbide tool compositions and those of $WTiC_2$ have the desirable thermal properties for tools to cut steel.

As a word of explanation why tool materials with thermal conductivities about 0.07 are preferable to those about 0.18 for steel cutting, it may be suggested that it is desirable to maintain the surface of the steel chip at a high enough temperature that it flows readily with minimum friction, and also that it may be more readily bent. If the tool material cools the chip too rapidly by conduction it is not so readily cut. Further observations of the detailed behavior of steel chips cut at high speed may yield further reasons, but the fact is that the tools with about 0.07 conductivity give better performance in cutting steel.

In making "Kennametal", the crystals of $WTiC_2$ are pulverized in ball mills with matrix forming metals such as cobalt and tungsten until the particles are smaller than may be resolved by the best microscope using ordinary light. By hydraulically pressing portions of this mixture in suitable molds, tool tips, balls, cylinders, tubes and other forms are made. The pressed blanks must be larger than the desired finished size to allow for shrinkage, usually about 22% lineally. This shrinkage takes place during the subsequent heat treatment in vacuum furnaces, necessary to obtain the product of very fine-grained, dense tool metal. It is produced in three grades of hardness by altering the percentage of cobalt, the lowest amount of which is 11% Co in the hardest grade "KH". The attached tabulation gives the properties of the three grades.

Hardness, Strength and Conductivity

Property	Alloy Designation		
	KH	KM	KS
Hardness, Rockwell A *(a)*	91	90.3	89.9
Rockwell C *(b)*	78	76.5	75.7
Transverse rupture strength *(c)*	224,000	275,000	310,000
Thermal conductivity *(d)*	0.075	0.110	0.120

(a) A scale, 60-kg. load.

(b) Diamond penetrator, 150-kg. load.

(c) Rectangular bar, 0.200 in. thick by 0.375 in. wide, supported on line centers $\frac{7}{8}$ in. apart. Strength computed by beam formula from load at failure.

(d) Calories per sec. per °C. per cm.

The modulus of elasticity in all of these compositions is about 58,000,000 psi., approximately double that of steel.

Unlike tungsten carbide cemented with cobalt, which is made by heating the pressed blanks in hydrogen, "Kennametal" is made in vacuum furnaces, under very definite conditions of temperature and pressure below 40 microns, mercury gage. The finished blanks have a surface appearing like a galvanized steel sheet, that is, with a very thin layer of cobalt condensed like frost on a window pane. This is because the cobalt was vaporizing in the hot furnace chamber at this degree of vacuum.

Since the shapes are hydraulically pressed, they shrink with true surfaces, and the molded blanks, as shrunk, are mounted by brazing into recesses milled in steel tool shanks without grinding of the seating surface. Brazing is preferably done with copper, although naval brass and silver solders have also been found useful. Since the modulus of elasticity of all steel is approximately the same, it makes little difference what steel is used for the shank as regards bending stresses within the elastic limit. S.A.E. 1045 has been found satisfactory unless a harder shank is desired for other reasons, whereupon an air hardenable steel would be selected.

To the domain of the tool engineer belongs the machining economies afforded by this new series of alloys. To mention only a few examples, the finish turning and facing of flanged axles and spindles of alloy steels is being done in the heat treated condition (in some instances at 351 Brinell, and in others as high as 461 Brinell) with precision, speed and economy. Automobile drive shafts of S.A.E. 5135 are machined at 270 ft. per min. and 0.012 in. feed of steel, at 302 Brinell hardness. Gear blanks of tough nickel steels are turned and faced in half the floor-to-floor time. Interrupted or jump cuts are taken in turning valve stems of 18-8 stainless steel, as well as cast steel. Steels are being milled with fast table feeds. Not only are these parts being fabricated at less cost, but the smooth untorn finish obtained by machining at high speeds with these carbide tipped tools is valuable for avoiding incipient cracks, initiating fatigue failure in such parts as locomotive tires. Some concerns machining heavy die steel forgings have found it desirable to use these carbide tools for the above reason.

CRITICAL POINTS

By the Editor

A COUPLE OF YEARS AGO when down at Barberton, JAMES HODGE of Babcock and Wilcox showed me some 18-8 stainless steel superheater tubing whose inside was covered with gossamer markings like the fine veining on a leaf — tiny cracks caused by no more severe a corrodent than very hot steam. Pressures and temperatures of this service were rather high, but similar cracks had infested the inside surfaces of thermowells in paper pulp digesters, whose only stress was the internal stress of quenching and whose corrodent was supposedly non-corrosive ethyl chloride. In both these failures the cracks crossed through the crystals, and thus were different from the intercrystalline fractures which characterize the classical examples of "stress corrosion", namely season cracking in brass and caustic embrittlement in carbon steel boiler plate. Some other recorded examples of disintegration of stainless steel were also intercrystalline — notably the vessel liners described by ENSLO DIXON of the Texas Co. in The Book of Stainless Steels, and cracking of solid stainless paper mill equipment by SAMUEL HOYT and MERRILL SCHEIL at the 1938 ASME Convention. HARRY IHRIG of Globe Steel Tubes Co. has also told me that all varieties of 18-8 and straight chromiums must be promptly annealed after heavy cold drawing, else the acid fumes coming from the pickling tanks may cause wholesale cracking.

Stress corrosion in stainless

HODGE and his associate JOHN MILLER (now on the faculty of Armour Institute) have discredited the comfortable assumption that the superheater tube troubles are caused by accelerated intercrystalline corrosion in a susceptible or non-stabilized alloy. Very few corrodents will crack crystals of stainless steel — in fact, the culprit in the superheater failure has not yet been found — but those that do are exceedingly pernicious. They find that moist ethyl chloride is one of these; also ferric chloride. DIXON adds to this list acid-treated naphtha at 110° F., and lubricating oil distillate with caustic at 500° F.

AS LITTLE as 10,000 psi. direct tensile stress and a 0.05% solution of ferric chloride will crack an austenitic stainless steel that is susceptible to intercrystalline corrosion, but even 18-8's that are stabilized with columbium or titanium will develop *transcrystalline* cracks in the above solutions if under considerable stress. MILLER and HODGE do not yet know just how much stress is required, but cold bending, welding, or quenching will cause trouble. The remedy is to use stabilized metal *and* cool it in a furnace from 1500° F. or more, thus stress relieving the completed structure. Even this will not prevent stress corrosion cracks alongside joints where 18-8 is welded to less expansible carbon or lower alloy steels, nor would the best stabilized 18-8 stand up against certain substances (at present ill defined) if the working stresses or stresses caused by temperature variations of normal operation reach, supposedly, the elastic limit.

Working stress must be considered

It would almost seem that the metallurgist, in giving industry the stainless steels with their remarkable resistance to general corrosion, has also provided metals that have an alarming susceptibility to concentrated attack in supposedly innocuous surroundings. Stainless is like a boy of robust constitution who has not yet run through the inevitable measles, chicken pox and mumps.

All the more reason for the greatest of care when installing stainless equipment; it is expensive and still subject to the distracting diseases of childhood. The part of wisdom is to depend on fabricators experienced in its vagaries, and to consult metallurgists who know about past successes and failures. Such a saying is so self-evident that it is trite, but nevertheless has been disregarded on occasion in the past by large purchasers who should know better than to buy on price.

TO ATLANTIC CITY, for the convention of the American Society for Testing Materials held annually at the cooling seashore during the rose-fever season. A brief paper by CLAUDE WAMPLER of A. O. Smith Corp. and NORVILLE ALLEMAN of University of Illinois on Fatigue Tests of Wire again emphasized the damage that hot-dip galvanizing does to the endurance properties of steel through roughening the surface and overlaying it with a weak metal where the strongest resistance to stress is desired. In these new tests heat treated bridge wire showed an endurance limit of ±132,000 psi. when the steel surface is polished, whereas it is only ±57,500 psi. in the galvanized state. While heat treated bridge wire is thoroughly discredited from failures during construction of Mount Hope and

Corrosion is worse enemy to bridges than fatigue

Detroit River bridges, a similar loss in endurance is experienced after dip galvanizing the cold-drawn wire, and this is the standard material for suspension bridge cables.

Extended studies of the broken wire from Mount Hope convinced WILLIAM SWANGER and GEORGE WOHLGEMUTH at the Bureau of Standards that the trouble was due to a fatigue failure at anchorage loops, so a statement was reassuring by LEON MOISSEIFF, a leading authority on bridge design, that civil engineers were not worrying about fatigue damage through vibrations in suspension bridge cables. Admittedly hot-dip galvanizing does affect the endurance limit but this is not a critical property, and galvanizing is a proven method of rust protection, which *is* a critical item. To his knowledge no troubles have been experienced with the physical properties or the corrosion of cold-drawn, galvanized bridge wire.

The only large American suspension bridge made with bare wire is the Williamsburg bridge between Manhattan and Brooklyn. Individual wires here were greased and the spun cables were compacted, covered by steel plates and textile-wrapped. In 1915 this covering was removed, the cable painted with red lead and then wrapped with galvanized wire. Recent examination indicates no corrosion except at one anchorage, where the cables splay out in poorly ventilated, humid compartments; seepage of uric acid from comfort stations had severely damaged one strand.

LARGER AND LONGER bridges are in the offing, and the relatively narrow suspension bridges will need flatter cables for horizontal and especially lateral stiffness. For this two principal things are necessary, in MOISSEIFF's opinion: Stronger and stronger wire for the main cables and lighter and lighter floor systems. To push the working load higher in the cable, the cold drawn wire must have a higher "true proportional limit" and bridge designers would welcome any such improvement. Lighter floor systems can come about through substitution of higher strength, corrosion resistant alloy steels for the usual plain carbon and low alloy structural steels. Strong aluminum alloys also have an important application here. Aluminum trusses and floor systems will also be economical in suspended spans of cantilever bridges, to save material in the supporting anchor spans, and in lift bridges for the saving in hoisting machinery. Much would depend on the relative costs of steel and aluminum. MOISSEIFF has computed that an ordinary 600-ft. highway span of aluminum would be competitive with steel if it could be fabricated and erected for 28c per lb., a figure not beyond the possibilities.

Aluminum versus steel for long spans

DO YOU REMEMBER the clever puppet show TONY SARG created for U.S. Steel Corp. for the 1937 National Metal Exposition at Atlantic City? Did you not wonder how the script ever got approved, containing as it did so many jests about stuffy happenings in the front office?

A similar unbelievable phenomenon is occurring in England, of all places, where wit is supposed to be *very* stuffy, if at all. High Duty Alloys, Ltd., of Slough (pronounced how?), a large producer of light alloy castings and forgings, has been publishing advertisements supposedly written by a simple-minded member of its staff, Mr. POBOTTLE. Nothing is sacred to Mr. POBOTTLE. Even when doing a technical article, he grasps his trusty pen and composes the following classic, entitled "Seriously Speaking":

Seriously speaking about magnesium

"There seems to have grown up a certain impression that we are incurably lighthearted. We would, therefore, point out that there are now about 1200 of us here, and of these about 1199 are extremely serious Technical Coves, who do the most amazing things with aluminum alloys. Our hearts may be light, but we take the greatest care to see that their Strength-for-Weight Ratio, and their Yield Point and their Resistance to Corrosion and all that, are absolutely first-class.

"Accordingly, if the Technical Gentlemen will kindly gather round, we should like to do a slightly heavier spiel than usual about a much lighter alloy than usual. To wit, Magnuminium 299.

"You may remember that one of the big snags about magnesium-aluminium alloys is that, unlike most of us, if you push too much liquor into them they cease to be tight. They suffer from that dread scourge, Microscopic Intercrystalline Discontinuities, vulgarly known as Little Holes. Moreover, the only known method of testing a casting for pressure tightness was to make the darned thing and submit it to pressure. Then, if it was all right, it was all right, and if not it was irritating.

"The scientific lads have been at work and have now evolved Magnuminium 299 which does *not* suffer from Little Holes, is very pressure tight indeed, and passionately resists corrosion. (We think the whole thing is rather a wangle, because apparently the boys, faced with the problem of making a non-porous magnesium-aluminium alloy, removed most of the aluminium and replaced it with tin.)

"Still, apparently the result is very notable, and clients may now have the satisfaction of knowing that if they have, say, a pump body made of Magnuminium 299, they will be able to *use* it as a pump body, and not merely as a fine mist-spray for the fruit trees. Anyhow, try ordering some from your grocer. The larger tin, as Mr. POBOTTLE asks us to remind you, costs very little more."

Establishment of the "S-Curve" by Davenport and Bain of the relations between transformation, time and temperature for a high carbon steel gave a clear and precise explanation of the so-called split transformations during quenching, discovered many years ago. Alloy steels, however, have "S-Curves" that do not look like an S, and the intermediate structure appearing between pearlite and martensite has inferior physical properties. A map of the conditions for plain nickel and chromium steels is now available and will help the metallurgist to avoid trouble.

INTERMEDIATE TRANSFORMATION IN ALLOY STEELS

BY W. T. GRIFFITHS, L. B. PFEIL AND N. P. ALLEN

Abstracted from Sec. 12 and 13, 2nd Report of the Alloy Steels Research Committee, Iron and Steel Institute, 1939

FRENCH WORKERS, about 25 years ago, observed a discontinuous lowering and "splitting" of the critical points in steel when increasing the cooling speed. If length changes or temperature evolutions were measured on a sample of carbon steel during a relatively slow cooling, an expansion or heat evolution could be observed at about 1300° F. — the well-known Ar_1 point. If cooling rates were raised from 1° per sec. to 500° F. per sec. the discontinuity on an automatically recorded cooling curve was lowered to the neighborhood of 1100° F., and this was called the Ar′ point. On still faster cooling, a second and much lower "point" (discontinuity) appeared on the curve and this was called the Ar″ point.

These phenomena have been intently studied by scientists in many lands, and the figure at extreme right shows the data on carbon steels which are common to all important researches. With increasing cooling rates Ar′ lowers in temperature, but what is more important, lowers in intensity, and is gradually replaced by Ar″, and this change is accompanied by the hardening of the steel and a martensitic structure. This structure contains a tetragonal lattice, the parameters of which vary continuously with the carbon content of the steel, and some retained austenite is always present. It is impossible to suppress this second transformation by rapid cooling alone in plain steel of any carbon content, even at cooling velocities up to 27,000° F. per sec. The temperature of the martensite reaction falls continuously as the carbon content of the austenite rises, from 750° F. at 0.2% carbon to 200° F. at 1.6% carbon, and is not greatly influenced by the rate of cooling.

Thus, plain carbon steels show only two types of transformation on continuous rapid cooling: Ar′ which produces constituents of a pearlitic nature, and the martensitic transformation which has hitherto generally been termed Ar″.

Similar work on alloy steels showed that some of them at certain quenching rates possessed not one but *two* transformations considerably below Ar′. Some typical dilatometer curves are also shown on the right hand page. In these the upper Ar″ occurs at about 800° F. and the lower Ar″ at about 400° F. Since the latter has been dubbed Ar‴ some confusion has been introduced. Both Ar″ and Ar‴ produce hard acicular structures, and some steels could be made to show all three points on a single quenching curve. Most investigators considered both Ar″ and Ar‴ to produce "martensitic" structures, and the splitting of Ar″ to be due to local differences in the composition of the steel.

Evidence is accumulating, however, that martensite is the product of Ar‴ transformation at lowest temperatures, fine pearlite (troostite) of Ar′ transformation at highest temperatures, and a wide variety of undesirable microstructures, generally acicular, of the intermediate transformation Ar″. For convenience these may be called "intermediate structures". Since the two points observed on the cooling curve of a rapidly cooled carbon steel correspond to the first and third points of the alloy

steel, and since in the carbon steel the middle point is never observed, the original notation should be revised to Ar′ and Ar‴, Ar″ being reserved for the "intermediate" point appearing in the cooling curves of alloy steel.

While the intermediate transformation does not occur in plain carbon steels on *continuous* cooling at any speed, it can be obtained in carbon steels by the *interrupted* quenching in hot metal baths, thus causing the transformation to take place during a long stay in the intermediate temperature range. Various names have been given to these microstructures. Griffiths referred to them as "troosto-martensite", while Davenport and Bain called them "martensite-troostite". Robertson used the term "intermediate structures". Names employed by others were "troostite-M", "pseudo-martensite", "quench pearlite" or "acicular troostite". Recently the term "bainite" has been employed in the United States.

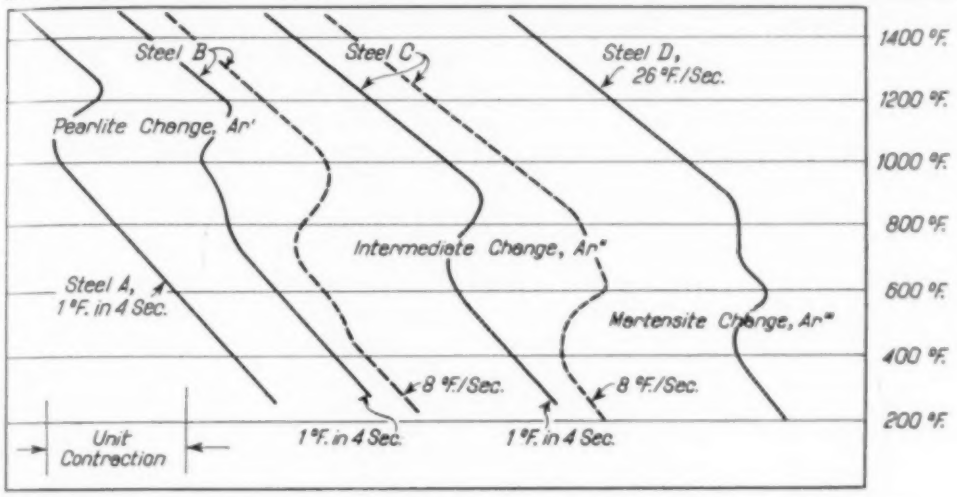
A good insight into the nature of Ar′ and Ar‴ was given by Davenport and Bain by their interrupted quenching experiments mentioned above. By quenching small samples of steel into metal baths held at constant temperatures, they showed that undercooled austenite had a characteristic rate of decomposition at each temperature, and that this rate had a maximum at 1000° F. and a second maximum below 250° F. Between these temperatures a region of low transformation velocity existed, so that if a steel were cooled in a cold medium at such a rate that it had no opportunity to transform at 1000° F. or above, it would not normally transform at any lower temperature until it had cooled to the temperature of the second region of rapid transformation.

Similar researches by others have shown that the behavior of some alloy steels is more complex. In fact, six general types of diagrams showing the transformation velocity at subcritical temperatures have been published, and these are reproduced in simplified form on page 160. Plain carbon steels and plain nickel steels are represented in diagram *(a)*. [In comparing these curves with those of Davenport and Bain — See METAL PROGRESS data sheet last month — it should be remembered that the American investigations plotted time horizontally, whereas on these diagrams velocity is plotted horizontally and a maximum in transformation time corresponds to a minimum in transformation velocity — Note by the Editor.]

In the steel represented by *(b)* the pearlitic and intermediate stages are separated by a clear interval of temperature, and do not differ greatly in velocity. The intermediate and martensitic transformations overlap, both changes being possible around 400° F. When the steel is transformed at a temperature just below the martensite point, part changes very rapidly to form martensite, and the remainder slowly by the intermediate mechanism.

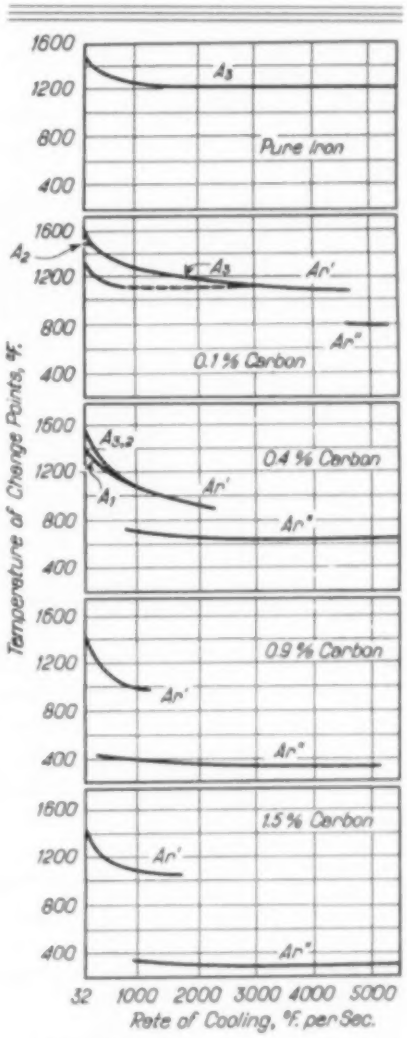
In *(e)* the pearlitic change is much slower than the intermediate change, whereas in *(d)* the reverse is the case, and the intermediate and martensitic changes are separated by a region of austenite stability.

In *(f)* the pearlitic and intermediate changes overlap,



Dilatometer Cooling Curves Showing Three Subcritical Changes in Alloy Steel

Steel A: 0.30% C, 3.0% Ni
Steel B: 0.33% C, 3.2% Ni, 0.62% Cr
Steel C: 0.34% C, 3.1% Ni, 1.2% Cr
Steel D: 0.32% C, 1.8% Mn



Transformations in Plain Carbon Steel Are Lowered and "Split" by Fast Cooling Rates

there being a minimum velocity at about 1000° F. but no clear separation of the two changes. Finally, in *(c)* there is a well-marked pearlitic change, but no change at all in the whole of the temperature region in which the intermediate change occurs.

The intermediate structure can be readily developed for micro-examination in an X3140 nickel-chromium steel, which belongs to the class illustrated by diagram *(e)*; it is therefore relatively easy to suppress the pearlite change. The intermediate structure consists of groups of parallel ferrite plates with carbide-rich material between. [It is well illustrated by Mr. Payson in July METAL PROGRESS, page 70 and 71, who proposes the name "Mathewsite" — Editor.] The scale of the structure depends on the temperature at which transformation takes place, the ferrite needles being finer and the carbon-rich particles smaller as the transformation temperature falls.

Its acicular nature is not always very obvious when the specimen has transformed completely in the intermediate range, but it is better displayed if the specimen is taken from the hot bath and quenched in water when only partly transformed. The unchanged austenite then transforms to martensite, which etches light in sharp contrast with the darker-etching intermediate product, and the "acicular" outlines of the latter become very noticeable.

It is sometimes difficult to distinguish between the intermediate product and martensite. In high carbon steels the etching behavior affords unmistakable means of differentiation, for the intermediate product becomes very black on light etching and the martensite remains brilliantly white. In low carbon steels the intermediate product etches more lightly on account of the greater proportion of ferrite in its constitution, and the martensite tends to etch darker, being much more easily tempered at the relatively high temperature at which it transformed.

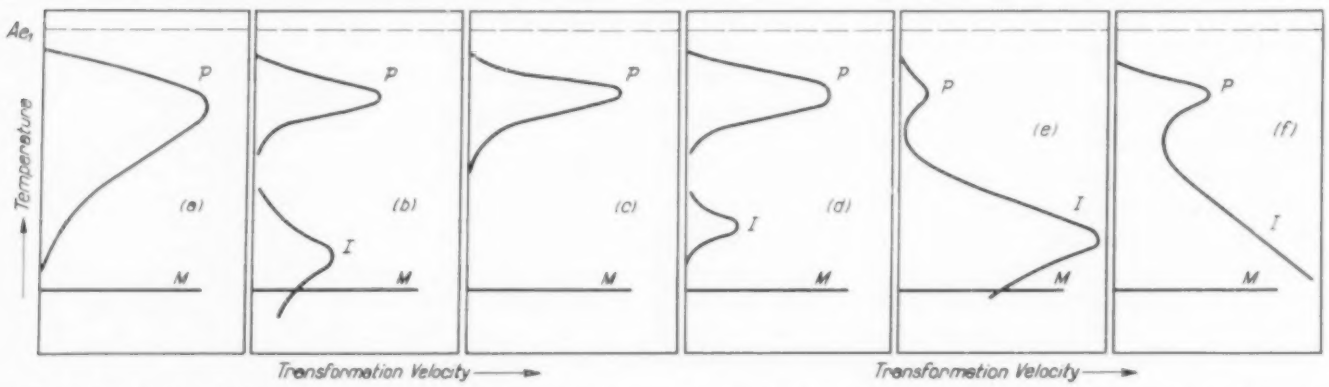
If the specimen is tempered it becomes very difficult to distinguish the two constituents, and this has led to the opinion by some that the intermediate product is simply martensite which has become tempered during the course of its slow formation. This opinion is no longer tenable, and evidence will be given later to show that the mechanical properties of the intermediate product differ in important respects from those of tempered martensite.

The atomic architecture of these decomposition products is a problem of the utmost interest to physical metallurgists. Mehl postulates that pearlite and bainite in carbon steels are both formed by nucleation and growth, pearlite being nucleated by cementite and bainite by the smaller crystal cell of ferrite. Martensite is formed by shearing movements in the crystal lattice wherein the austenite transforms *en bloc* to a strained ferrite lattice (tetragonal). He inquires about "the product of decomposition between the temperature at which bainite ceases to form and ordinary martensite forms, dark-etching and acicular in structure", and tentatively suggests that it is tetragonal martensite that tempers (decomposes into small ferrite and cementite crystals) as rapidly as it forms.

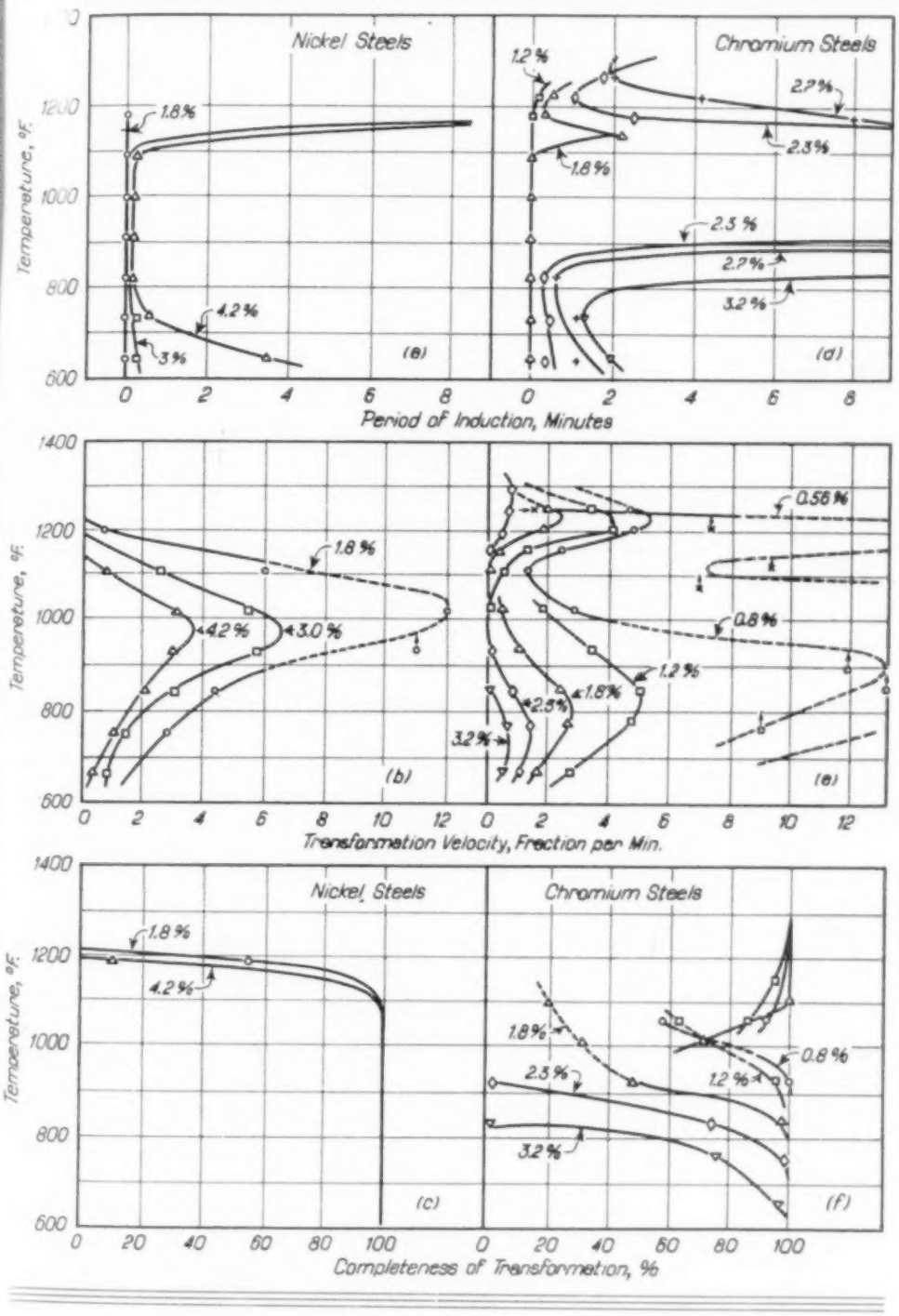
Wever and his colleagues at Kaiser Wilhelm Institute, who have long worked on the problem, have a somewhat different explanation of the microstructures:

"In the first stage, between 1200 and 1000° F., the transformation follows the same processes as in slow cooling . . . . pearlite forms and ends the transformation.

"In the second stage, between 950 and 250° F., the austenite loses the ability for the direct separation of cementite. Supersaturated ferrite first crystallizes from the austenite . . . . and decomposes very quickly into stable, nearly carbon-free ferrite and cementite, which acts as a nucleus for the further precipitation of cementite from the austenite. In the lower temperature range of the second stage, on account of insufficient diffusion, cementite no longer forms, and at the same time the stimulation



Transformation Velocity of Various Steels at Subcritical Temperatures. P represents the pearlite change, I the intermediate, and M the temperature below which martensite will form at a very rapid rate



Transformation of Pearlite and Intermediate Constituent in Nickel Steels (Left) and Chromium Steels (Right) Containing 0.30% Carbon; the Martensite Transformation Is Not Shown

of cementite precipitation from the austenite also ceases. The carbon separates in an unknown form, which is converted to cementite only by tempering.

"In the third stage, below 250° F., the austenite changes without alteration of the composition into tetragonal martensite, which is no other than supersaturated ferrite.

"Supersaturated ferrite in the second and third stages always separates in the form of needles."

It would be expected that these differences would be accompanied by differences in mechanical properties. Such differences are in fact found.

In the X3140 steel above mentioned the tensile, ductile and impact properties uniformly increase after being cooled at rates up to 3½° F. per sec., but after cooling through 1500 down to 1100° F. at 5° F. per sec. (after which the intermediate microstructure is predominating) the ductility and impact values are much reduced. The brittleness of this product is not due to intermingled martensite, for similar physical properties are obtained when the intermediate constituent is produced by the complete transformation of austenite at constant temperature in a lead bath.

Further, if a steel transformed to intermediate constituent is tempered at the temperature of the original lead bath treatment, and compared with a steel which has been rendered fully martensitic and tempered at the same temperature, the latter is found to be the tougher. For example, two blanks of a manganese-molybdenum steel gave the following impact values: Oil quenched and tempered at 850° F., 21 ft-lb.; transformed in lead at 850° F., cooled in air and tempered at 850° F., 11 ft-lb. For another instance, seven engineering alloy steels, transformed at 700 to 800° F., had very low Izod impacts of from 4 to 20 ft-lb.

It must therefore be concluded that the low impact strength is a property of the intermediate product itself. If a steel is liable to transform in the intermediate range, and particularly if its velocity of reaction is higher in this range than in the pearlitic range, it should not be used without tempering (unless the cooling rate is slow enough for fine pearlite to form without any of the intermediate product). The practice of specifying alloy steels for use in the normalized condition can be dangerous with some steels, while being quite satisfactory with others.

Tempering causes some improvement in the properties of the intermediate product. Five good

alloy steels were compared in the lead quenched and oil quenched state, all samples having later been drawn at 1200° F. Using the oil quenched and drawn samples as the basis, the lead quenched and drawn samples lost, on the average, 21% of the proof stress, 10% of the ultimate, and 5% of the impact values. Four other steels, when treated in a similar program except that the tempering was adjusted to give equal tensile strengths, also showed inferior properties in the lead quenched samples as follows: Proof stress lost 18% and impact 35% of the values possessed by the oil quenched and tempered samples.

Four other steels, treated in parallel to equal hardness of 250 Brinell, were then tested for endurance strength at 10 million reversals; again the lead quenched and tempered were consistently inferior; their average loss in endurance limit was 10%.

It appears, therefore, that alloy steels may differ from carbon steels in that, while the latter may transform during a continuous quenching operation in only two temperature ranges, the former often can transform in one or more of three temperature ranges. Suppression of the pearlite change in alloy steels does not necessarily prevent other changes until the low martensite-producing temperatures are reached. The intermediate structure is generally of inferior properties, and to avoid its presence it is not only necessary to know whether a given quenching procedure will avoid transformation in the pearlite range, but also where, and to what extent, the steel will transform at lower temperatures. Complete information can be obtained only by determining the transformation-velocity versus temperature curve for the steel.

The authors have for some time been deducing such curves from a study of accurate and sensitive dilatometer experiments. The technique involves the plotting of length vs. time curves from movie films showing the dials of an Ames gage and a time clock while the sample is being quenched and held in a bath of uniform temperature. Comparison of such curves with similar curves of steels which transform completely in a known manner under the given condition (or do not transform at all) allows the investigator to determine the incubation time, the rate of transformation, and its completeness. These three characteristics are necessary to characterize a given steel. Some results on nickel and chromium steels are given on page 161.

The *period of induction* represents the time required for transformation of the first 10% of austenite (a figure arbitrarily chosen, but by this time the intermediate change if any will usually be approaching its maximum speed).

Transformation velocity is given by the mean slope of the transformation curve between 10% of austenite transformed and 75% transformed, when the curve is plotted logarithmically. In the intermediate change this slope is usually constant, and represents the proportion of the residual austenite transformed per unit time. (The speed of the martensitic change is too fast for this technique.)

Completeness of transformation can be estimated roughly under the microscope for the pearlitic and intermediate ranges (but not for the martensitic change on account of the presence of residual austenite).

Transformation of Nickel and Chromium Steels

An example of the use of these methods in studying the influence of alloying elements on the transformation behavior of steels is given in the last figure. From this the following is deduced:

The effect of nickel in a plain nickel steel is twofold. It lowers the transformation velocity progressively at all temperatures. The pearlitic and intermediate changes are equally affected and the temperature at which the maximum transformation velocity occurs is much the same as it is in plain carbon steels, namely 950 to 1050° F. Long periods of induction are found in high nickel steels at low transformation temperatures.

Secondly, nickel lowers the temperature at which the pearlitic change begins. Nickel steels with 3% or more of nickel do not transform completely at 1200° F. within many hours, but at no temperature below 1100° F. does the transformation fail to go rapidly to completion. Above the temperature of maximum transformation velocity pearlitic structures are produced, and below it structures of the intermediate type. In this respect plain nickel steels (within the range of composition which has been studied) behave essentially in the same way as plain carbon steels, except that the transformation rates are lower.

The effect of chromium is different both in degree and in kind. It retards and raises the temperature of the pearlite change and retards and lowers the intermediate change, exerting a particularly strong effect in the neighborhood of 1000° F. When 2.3% of chromium is present the two changes no longer merge, as they do in plain carbon and nickel steels, and a region of high austenite stability appears and becomes wider as the chromium content increases. The gradual divergence of the temperature ranges of the two types of change is seen particularly well in the *period-of-induction* curves for steels with 1.8 to 3.2% of chromium. Steels with less chromium have short periods of induction throughout the whole temperature range. Chromium has a rather greater effect on the pearlite change than on the intermediate change, and since rates of cooling in practice are more rapid at 1200° than at 800° F., the effect of chromium is to produce steels which prefer to transform in the intermediate range.

(Continued on page 188)

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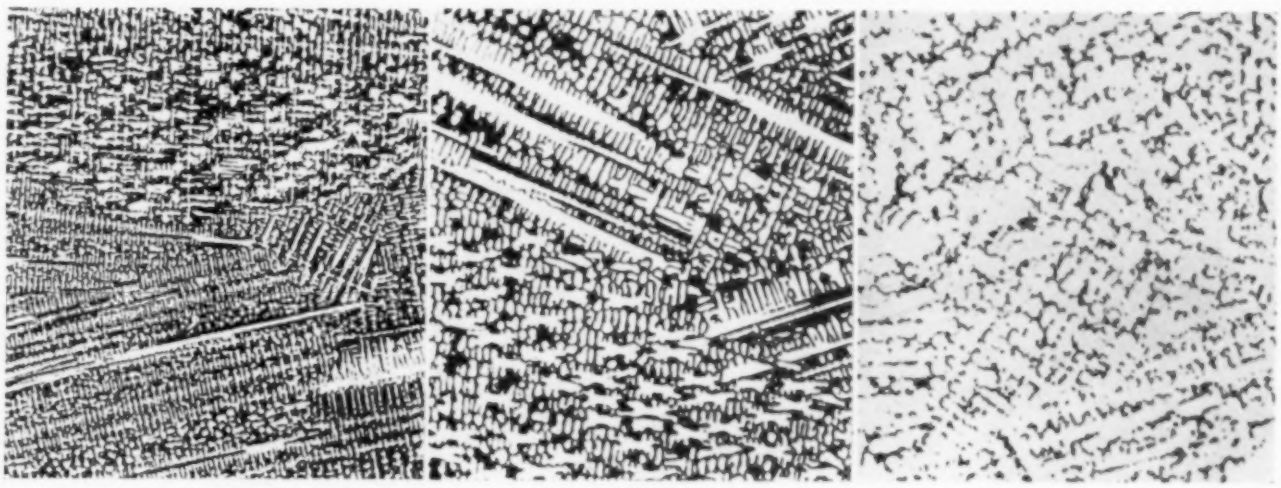
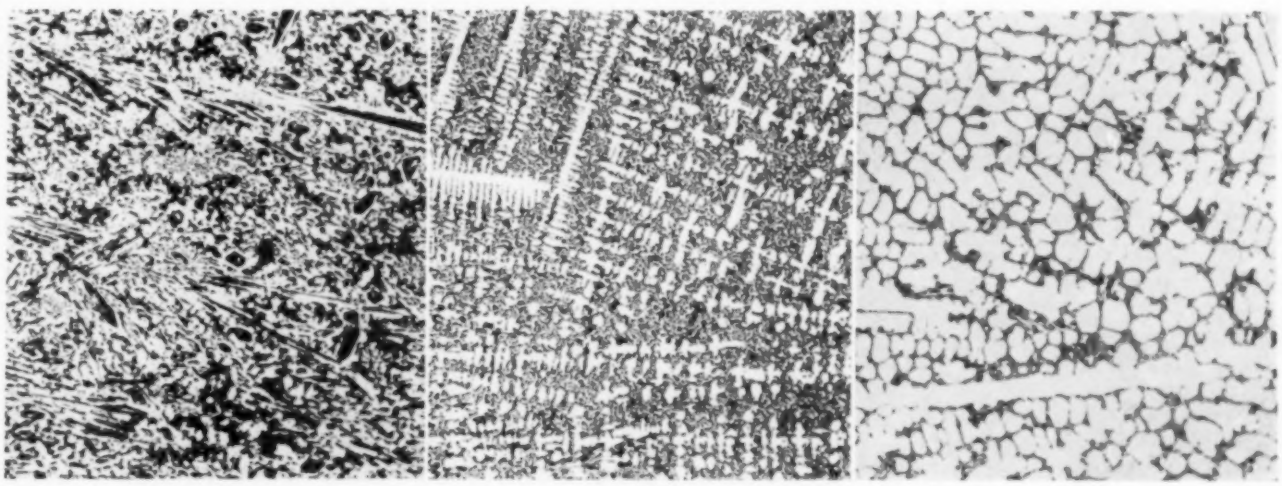
Structure of Co-Cr-W Alloys (Stellite)

Micros at 100 diameters by Union Carbide and Carbon Research Laboratories



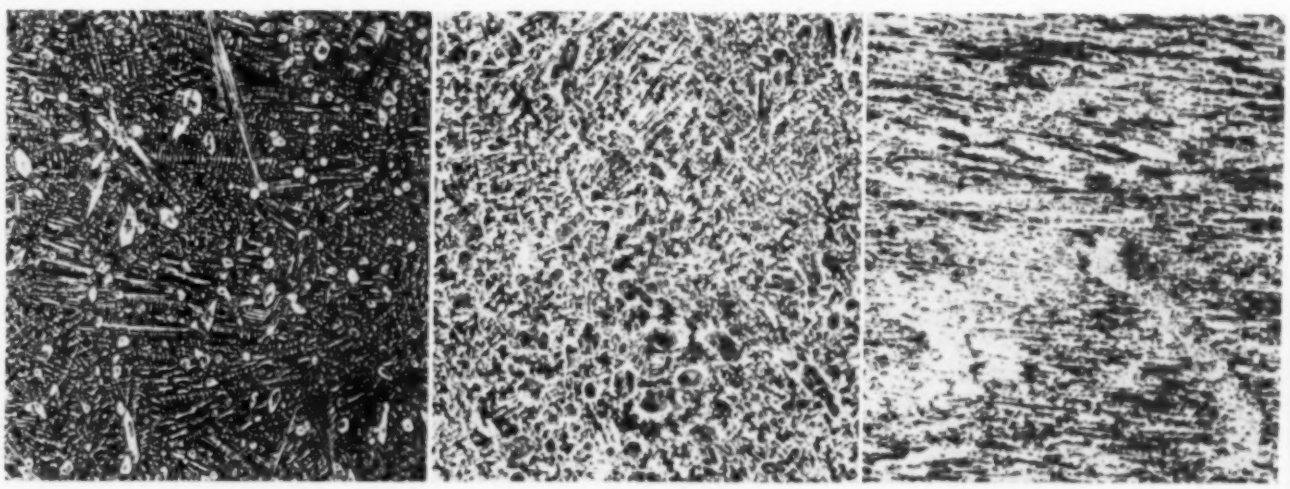
No. 1 Alloy | No. 12 Alloy* | No. 6 Alloy

Metal-Arc Welded Samples



No. 1 Alloy | No. 12 Alloy | No. 6 Alloy

Oxy-Acetylene Welded Samples



*J-Metal As-Cast** | *"2400" Cast Alloy* | *No. 6 Alloy, Rolled**

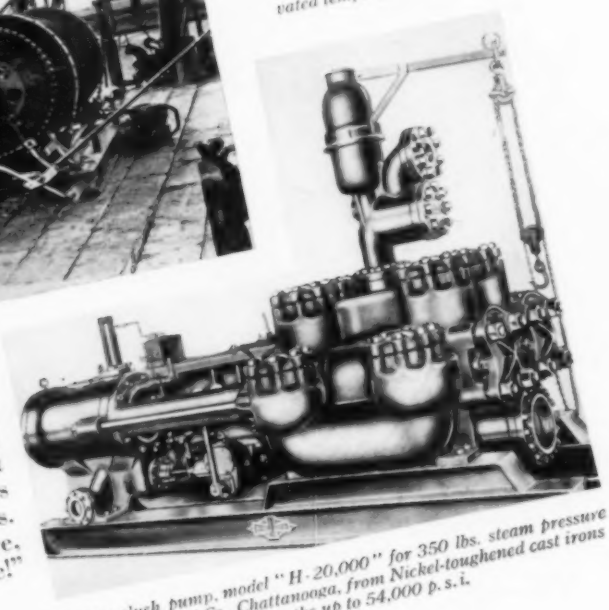
All specimens etched with Murakami's reagent (see page 725 ⊕ Metals Handbook, 1939 edition).
*Sample re-etched with HF plus HNO_3 to whiten carbides.

Oil field advantages FORETOLD *by physical tests*

CAST NICKEL IRONS

Mechanical testing is important at Wichita Falls Foundry & Machine Co. Stocks are maintained of oil field equipment, particularly Diesel pistons, liners, heads and rings of Nickel cast iron. Nickel alloyed irons provide greater toughness and strength at elevated temperatures.

Reed Roller Bit Co., Houston, uses Nickel-chromium-molybdenum cast iron in its "Type 101" rotary engine. Tensile strengths show 55,000 p. s. i. Nickel inhibits growth at superheat temperatures.



Duplex slush pump, model "H-20,000" for 350 lbs. steam pressure built by Wheland Co., Chattanooga, from Nickel-toughened cast irons with minimum tensile strengths up to 54,000 p. s. i.

Foretelling the log sheets of every drilling crew is another sheaf of reports—records of physical tests made upon all material to be used in the field. In testing labs, as on derrick floors, oil men agree that Nickel alloyed cast irons do more work at lower cost per foot and per year.

Tensile strength...hardness...wear resistance...strength at elevated temperatures...resistance to growth...dense-grained structure to maintain pressure-tightness...toughness to resist shock stress. The heightened physical properties of cast irons alloyed with Nickel are indicated by scientific testing methods. Your horny handed driller sums it all up when he says, "Sure, Nickel Iron's O.K.—never gives us no trouble!"

THE INTERNATIONAL NICKEL COMPANY, INC., 67 WALL ST., NEW YORK, N. Y.

LETTERS FROM HOME AND ABROAD

SPECTROGRAPHIC ANALYSIS OF STEEL

SHEFFIELD, ENGLAND

To the Editor of METAL PROGRESS:

The value of spectrographic analysis as a means of determining the presence or absence of impurities in metals or compounds was realised years ago but it is only comparatively recently that attempts have been made to use the spectrograph as a routine method of analysing metals.

Apparently the first metallurgical applications had a rather limited scope, one suggested purpose being to sort out rapidly alloy steels from carbon steels and in addition, to obtain a rough approximation of the alloy content. For such purposes, visual examination of the spectra was deemed sufficient and the apparatus itself was made as sturdy as possible so as to fit it for workshop use. It was not long, however, before successful attempts were made both in England and America to obtain much more accurate quantitative data, particularly in the commercial examination of non-ferrous alloys.

In 1933, the British Non-Ferrous Metals Research Association published a monograph entitled "Metallurgical Analyses by the Spectrograph", by D. M. SMITH, which recorded the results of eight years of systematic study of spectrographic methods for the analysis of non-ferrous metals and alloys. In many ways, these results were remarkable; they demonstrated the ease and accuracy with which minute amounts of many impurities could be estimated.

For example in the analysis of lead, amounts of copper could be determined down to 0.0002%, bismuth to 0.0005%, cadmium and silver to 0.0008%. If it was merely a question of deciding whether an impurity was present or not, some of these figures could be reduced considerably. For instance it was claimed that about 0.00005% cadmium and 0.0001% copper or silver could be detected with certainty in lead. SMITH considered that spectrographic methods were most effective in the region of traces, and stated that about 1% might be taken as the upper limit for practical purposes.

Less was heard at that time of the application of the spectroscope in the iron and steel industry. From an article in METAL PROGRESS in June 1933 one would infer that the method was in use in at least one large American plant for alloy steels, and 2% was placed as the upper limit for rapid determinations of chromium, manganese, silicon, titanium, nickel, vanadium, tin and copper. In England its usefulness was being carefully investigated by certain workers, and led to methods that have been in use by the Admiralty for some time.

Detailed information about the new Admiralty Laboratory in Sheffield is now available. Particularly the value of spectroscopic analysis in a routine laboratory, dealing with many hundreds of samples, is contained in a paper "Some Applications of the Spectrograph to the Quantitative Analysis of Ferrous and Non-Ferrous Metals" by F. G. BARKER (chief chemist of the Admiralty Laboratory) which was presented at the May meeting of the British Iron and Steel Institute. Briefly, BARKER shows that satisfactory methods have been evolved for the determination of the amounts of silicon, manganese, nickel, chromium, molybdenum and vanadium ordinarily present in carbon steels or the alloy steels regularly used when high tensile strength

is required, and also for the determination of small amounts of titanium, cobalt, copper and aluminum.

A feature of BARKER's methods for the analysis of steel is the use exclusively of a high tension spark discharge. He found that the spectra obtained from the ordinary low voltage arc did not yield reliable quantitative data. The spark is passed between the metal to be examined and a pointed electrode of graphite under standardized conditions; the spectra produced are photographed on super-sensitive panchromatic plates, exposure and development being also standardized.

On account of the great number of lines in the iron spectrum, it was found essential to use a spectrograph of large size, namely, one giving a spectrum about 30 in. long, between about 2000 and 8000 Ångström units. The wide dispersion thus obtained enabled adjacent lines, differing in wave length by as little as 0.3 Å, to be well defined and separated.

Quantitative methods depend on determining the relative density, in the negative, of a selected line due to the alloying metal, and a nearby line, having approximately the same density, produced by the parent metal. These comparisons are made by means of a photo-electric micro-photometer which consists essentially of a light source, a carriage to take the plate, a slit, a photo-electric cell and a mirror galvanometer with scale.

It will be appreciated that the development of these methods has necessitated a great deal of investigation and this, whether it led to positive or negative results, is described in detail in BARKER's paper. It is impossible, in this note, to give even a brief account of this very interesting work but it will repay careful study by all who wish to follow the subject. Suffice it to say that he claims that silicon up to about 0.3%, manganese to 2%, nickel to 4.5%, and vanadium to 0.25% can be estimated with an average accuracy of plus or minus one-twentieth of the actual amount present, and that titanium, copper, cobalt and aluminum in amounts up to about 0.1% can be determined to $\pm$ 0.02% or less, and finally that these determinations can be done with a speed greatly in excess of that possible by ordinary chemical methods.

As an instance of speed, it is said in the paper that one man, in less than one day, can analyse 12 samples of nickel-chrome-molybdenum steel for silicon, manganese, nickel, chromium, molybdenum, vanadium, aluminum and copper, obtaining results with the accuracy mentioned above. It seems probable that most steel works metallurgists will agree that this degree of accuracy is ample, while there can be no doubt that few analysts would wish to make the same number of determinations by chemical methods in the same time!

One sees, by the account of the spectroscopic laboratory at the Ford factory, printed in July METAL PROGRESS, that actual developments in America are also well advanced.

J. H. G. MONYPENNY
Brown, Bayley's Steel Works, Ltd.

NAMES FOR HARDENABILITY TEST

CLEVELAND, OHIO

To the Editor of METAL PROGRESS:

Before the polls are closed, may I add a few words to the discussion of "hardenability" nomenclature?

Fortunately, the uncertainty or variation in usage of the word "hardenability" itself seems to be decreasing; by general acceptance this term is now limited to "depth hardening response", as distinguished from any numerical measure of surface hardness. Hardenability therefore is a volume property.

The two fundamental types of hardenability tests should, it seems to me, be given as brief and descriptive titles as possible. My own preference runs to "end-quench test" and "end-quenched hardenability" for the method of JOMINY and BOEGEHOLD as being concise and clearly indicative, but it is hard to resist the portmanteau "Jominability" now being used in the secluded privacy of several laboratories. For the alternate type of test, "round-quench test" seems most suitable, although "section-quench test" is acceptable. ("S-A-C" is, of course, simply a rating or classification method.)

The reasonable and logical objection may be made that *hardenability* is a basic, fundamental property, and that end-quenching or round-quenching does not show this property but an integration of the effects of heating time and temperature, previous structure, quench, and section imposed on hardenability. This is true, of course. Perhaps we should say (thus violating our desire for brevity) "end-quenched hardness gradient plot" and then explain that we don't mean hardness, either, because our test hasn't determined hardness!

GORDON T. WILLIAMS
Metallurgist, Cleveland Tractor Co.

Radiographs of Irregular Sections

Schenectady, N. Y.

To the Editor of Metal Progress:

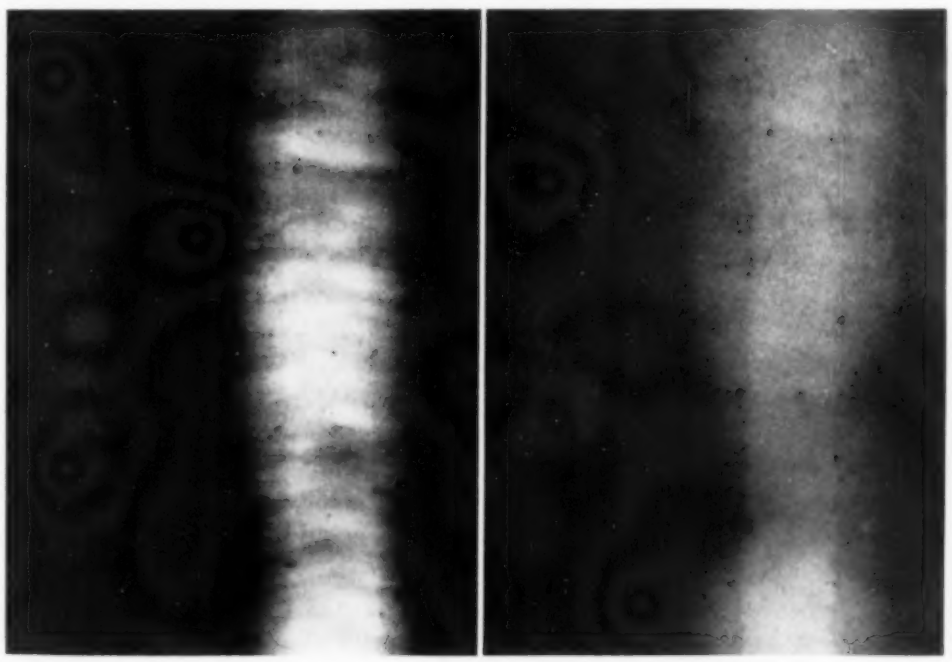
All industrial radiographers have been hard put to devise means of investigating articles of varying thickness; proper conditions to radiograph the thinner portions will show little or nothing about the heavier ones, and if the exposure is lengthened for the heavy section, the plate under the thin sections is badly over exposed.

One way of overcoming this difficulty has been to use a film of low contrast value, special filtering screens, and relatively long exposures. Even so, the X-ray pictures would lose considerable detail and contrast. Another way was to immerse the article under examination in a solution of lead acetate or similar compound which is much more opaque to X-rays than is air. Such liquids improved the sharpness and contrast of the radiographs, but they still left room for improvement since none of the liquids used was of opaqueness approximating the metal. A third method has been by building up a block of lead-bearing putty around the object. Non-uniformity of the putty, however, has been a handicap with such technique.

We have found that most of these difficulties are removed by the use of fine metallic shot. The accompanying radiographs of a ripple weld containing a multitude of blow holes show the improvement with "blocking" of copper shot. Shot of steel or non-ferrous alloy may be utilized when material of other X-ray opacity is desired.

The shot must be exceedingly fine. In our work the tiny spheres of copper are on the order of 5 mils diameter; approximately 10,000,000 to the cubic inch.

C. D. Moriarty
Works Laboratory, General Electric Co.



Immersion in Fine Copper Shot Masks Effect of Ripples on Surface of Weld and Records Many More Interior Defects on the Radiograph

Arsenic in Steel

Krefeld, Germany

To the Editor of Metal Progress:

The increasing use of German iron ores is introducing a larger proportion of arsenic in our finished steel, since the ore contains up to 0.20% and this is transferred to the pig iron and eventually to the finished steel. While it has already been shown that arsenic when present in proportionately high percentages exercises a definite and indeed most detrimental effect on various steels, special attention was given to the problem of smaller amounts, since the percentage in German steels is constantly increasing because of the re-use of scrap — arsenic not being removed in the metallurgical processes at present in use.

As a general rule, arsenic up to 1% will slightly increase the tensile strength and yield strength. Elongation is frequently unchanged, but usually only a minor fraction is required to reduce markedly the reduction of area and the Charpy impact value. More specific data on several steels follow:

Soft steel — up to 0.9% arsenic has no influence on forgeability or rolling properties. Aging is unfavorably influenced; while a 0.12% arsenic steel after aging (10% cold reduction, 2-hr. anneal at 500° F.) shows a sharp decrease in notch toughness only below freezing, a 0.24% arsenic

steel loses toughness at room temperatures.

Medium steel (0.45% carbon) likewise presents no difficulties in hot and cold work up to 1% arsenic. In the quenched and tempered condition notch toughness decreases above 0.25% arsenic, but only sets in above 0.55% arsenic in the normalized steels. No difference in toughness is caused by slow (furnace) or rapid (air) cooling; the tendency toward temper brittleness is therefore not aggravated.

Carbon tool steel — It should be noted first of all that 1% arsenic raises the transformation temperature about 35° F. Consequently the steel with higher arsenic content requires a higher quenching temperature. With arsenic higher than 0.20% the depth of hardness is decreased and the hardened zone loses its velvety luster and takes on a dull gray hue; instead of the ductile, fibrous fracture, they have an angular, brittle fracture. Increase in sensitivity to overheating is noted above 0.20% arsenic.

Chromium-nickel steel (0.33% C, 0.75% Cr, 3.75% Ni) — The structural constitution of the chromium-nickel steels is apparently unaffected by arsenic. When oil quenched and tempered to a strength of 175,000 psi., losses in ductility and notch toughness can be noted with as little as 0.15% arsenic. When this steel contains 1% arsenic it is completely brittle.

When drawn at a higher temperature to the low tensile range of 135,000 psi., the steel shows similar losses in toughness. Marked variation occurs in the reduction of area with slow cooling (in the furnace) and with rapid cooling (in air). Thus arsenic not only lowers the toughness of the chromium-nickel steels but also renders them brittle to an extreme degree.

Chromium-molybdenum steel (0.30% C, 1.10% Cr, 0.20% Mo) — No influence was noticeable on the properties either in the high tensile nor in the low tensile range. Likewise no influence was observed on the temper brittleness.

The grade of this steel utilized for welding (aircraft structures) can be rolled without trouble down to 20-gage sheet. Various welding tests showed that 0.55% arsenic did not induce welding cracks, thus confirming previous observations made on unalloyed steels, using a proportionately high arsenic content. In contrast to this, flame welding is impeded by as much as 0.15% arsenic and with higher percentages is entirely impossible. Good joints, however, can be obtained with the electric arc.

Creep resistant steel (0.16% C, 0.88% Cr, 0.45% Mo) — This steel is used mostly after a very high draw, and in this condition the effect of arsenic is less marked than at higher tensile strength. Up to 0.41% — the limit investigated — the tendency toward temper brittleness is not enhanced by the presence of arsenic. The creep strength is neither raised nor lowered.

High speed steel (12% or 18% W) — Although addition of arsenic up to 0.78% has no effect on hardenability, cutting efficiency is impaired even by small amounts of arsenic. In the 18% W steel the cutting efficiency is reduced about one fifth by 0.50% arsenic, and the 12% W steel containing 0.78% arsenic has only half the cutting efficiency of arsenic-free high speed.

Distribution of arsenic in the ingot — In an unkilled ingot of soft steel arsenic segregated just about as much as phosphorus. Local concentrations must be calculated as about double the average content. Blowhole formation is not affected.

In a 2½-ton killed ingot, on the other hand, no segregation of arsenic was observed; variation in arsenic content between edge and core was 0.22 to 0.25%.

As a general conclusion, therefore, it may be said that arsenic requires special attention, particularly in the highly alloyed and highly refined steels, even when present in small amounts.

H. Hougardy
Research Laboratories, Deutsche Edelstahlwerke

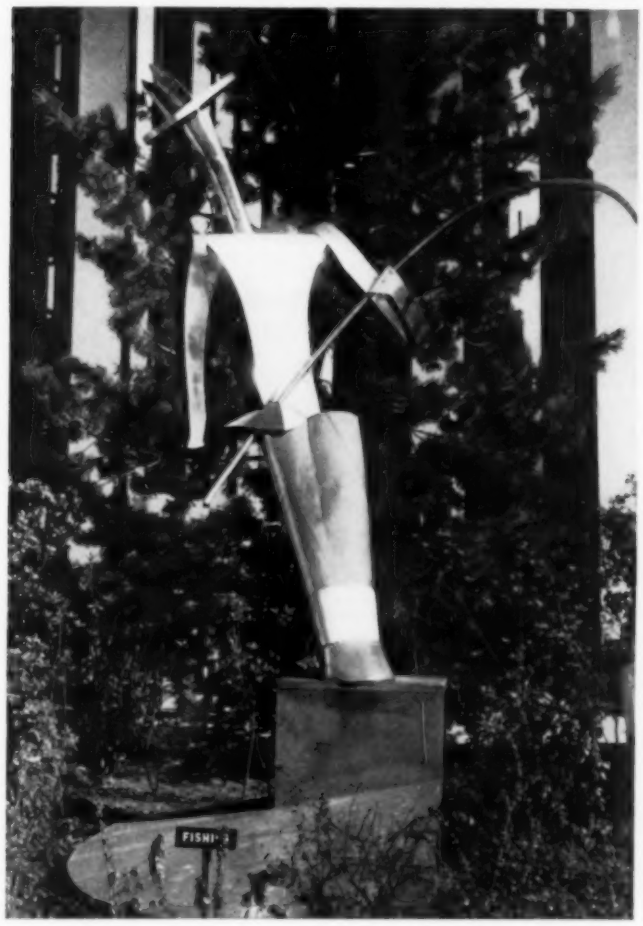
But Is It Art?

San Francisco, Cal.

To the Editor of Metal Progress:

The World's Fair at the Golden Gate has its good exhibits of futuristic statues, even though the principal architectural motif harks back to the art of pre-historic Americans.

Attracting considerable comment for their utmost simplicity and sweep of movement are five outdoor statues entitled "Fishing", "Camping", "Mountain Climbing", "Skiing", and "Horseback Riding". They stand 16 ft. high in the Federal Court. By skilful bending of the metals and careful selection of materials, such qualities as speed, strength, skill, balance, patience, and relaxation are expressed with unusual emphasis. Texture and color is also in keeping with the subject matter. The camper has well tanned limbs of sheet bronze, and an aluminum fish is in the frying pan. The alpinist climbs a mountain (12-gage plate), shaped on a power press and welded together, covered



"Fishing" — One of a Group of Five Amusing Sheet Metal "Sculptures" at the San Francisco Fair. Anglers will recognize the complete relaxation and balance necessary for a successful catch

with patches of brass and frosted aluminum to portray rocks and snow.

The original models, done in metal on the scale of one inch to the foot, were fashioned by Michael Chepourkoff from sketches by the architect Timothy Pfleuger. Actual construction was done by Fire Protection Products Co. of San Francisco. The completed metal models were taken apart in the drafting room and full sized paper templets made from the sections. For most of the sheet metal, particularly the brass and aluminum, 22 gage was used, but for some of the heavier framework 12-gage steel plate was necessary. To get away from any feeling of heaviness in the statuary as little of the thicker plate as possible was employed.

All the groups were constructed complete in the plant and then knocked down for reassembly on the site, where they were placed in garden settings. Exposed surfaces were well polished and lacquered. CHARLES F. BERRY

THE STRUGGLE AGAINST CORROSION IS ORGANIZED

PARIS, FRANCE

To the Editor of METAL PROGRESS:

In the past 20 years studies concerning chemical corrosion of metals and the methods of resisting it have undergone considerable development, and commissions or corrosion committees have been created in such various countries as Germany, England, Belgium, France, Holland, and Sweden. In the United States 18 technical societies and other organizations interested in the study of corrosion have just grouped together to form the American Coordinating Committee on Corrosion.

These various societies or commissions organize technical and scientific meetings where the various problems connected with corrosion are discussed. Thus, last year, such meetings were held at Düsseldorf, Detroit, Zurich and Berlin.

Up to the present, however, none of these meetings have been as international in character nor as broad as the one that was held in Paris last November. It was in fact the first true corrosion congress thus assembled and its success far exceeded expectations. More than 550 participants representing 15 nations were registered and 70 reports were presented and discussed.

These reports and communications may be grouped under the following problems:

Studies and tests — can the corrosion resistance of metals and alloys be predicted?

Welds and assemblies considered from the point of view of corrosion.

Pure metals and corrosion.

Surface condition and resistance to corrosion; passivity.

Study of protective films and their formation.

Pitting.

Protective methods for magnesium and light alloys.

Mechanism of intergranular corrosion and influence of stresses.

Respective roles of chemical and electrochemical corrosion in various types of attack.

Application of paints.

Materials resistant to corrosion.

Water treatment to avoid corrosion of pipes and containers.

An exposition, visits to plants featuring metallic constructions resistant to corrosion, and to corrosion test stations, and lectures to describe and explain the methods used to com-

This Photograph of a Welder, Made by C. A. Barnes of Battelle Memorial Institute's Staff, Attracted Much Attention at the Photographic Exhibit at the Recent ASTM Convention

bat corrosion completed the program, so that the meeting assumed three different purposes — to understand, to instruct, and to control, corresponding to three stages that must succeed each other chronologically: *(a)* Scientific study, to understand the phenomena, their mechanism and laws, and to deduce their consequences; *(b)* instruction and dissemination of information derived from the conclusions and consequences of these scientific studies; *(c)* regulation, provided mainly by tests and laboratory control.

It was essential that such a program, which marked a date in the history of the struggle against corrosion, should be continued so that its effect might be fruitful and permanent. Resolutions embodying the following recommendations were therefore unanimously adopted during the closing session:

1. That an international meeting assembling all those who are interested in corrosion of materials be held every year in a country desirous of acting as host.

2. That this international meeting be held without interfering with national meetings, whose actions and conclusions would of course be considered.

3. That it coincide, as far as possible, with other international meetings or congresses of industrial chemistry or material testing, so as to minimize travel and organization expense.

4. That this international meeting include general conferences discussing the actual state of a problem, either in a particular country or concerning a particular aspect.

5. That an international committee be appointed to carry out the above program.

It is not necessary to emphasize the importance of these resolutions establishing the principle of concerted and continued action, and it is to be hoped that the work so inaugurated will be energetically pursued in a cooperative spirit. Thus the struggle against corrosion, formerly organized on a national scale, would proceed on an international scale.

It is to be hoped that the endeavors of men and the means that science places at their disposal will in the future be directed toward the universal struggle against the general scourges of humanity — those that tend to destroy indi-

viduals (the fight against illness, particularly tuberculosis and cancer), those that tend to destroy their nutriment (struggle with the diseases and parasites that attack domestic animals and plants), and those that destroy their works (the fight against corrosion, that malady of metals and other materials of construction).

ALBERT PORTEVIN
Professor, Ecole Central des Arts et Manufactures

MACRO-ETCH REAGENT
TO SHOW SOFT SPOTS

IPSWITCH, ENGLAND

To the Editor of METAL PROGRESS:

The writer was very interested in the letter from H. HOUGARDY which was published in the May issue of METAL PROGRESS, and which outlined some of the work carried out in Germany in connection with high speed steels. The last few words of the letter, namely, "assuming always that each steel tool is properly fabricated and heat treated", brings to mind an investigation recently made concerning the service life of high speed steel taps.

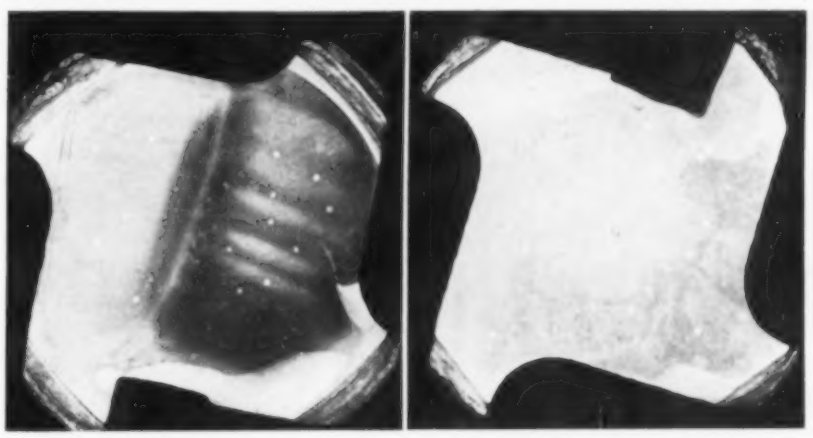
In an organization which has to tap or thread millions of malleable castings in the course of a year, there arise from time to time queries as to why some taps give longer production service, or cutting life, than others. These problems have sometimes been associated with the composition of the steel, but more often than not it is a matter of correct or incorrect heat treatment of the tools in question.

The recent case which is referred to above concerns the difference in cutting life between two taps, one of which threaded 30% more castings than the other. Chemical analysis of the steel showed that the material was almost identical in composition, and hence it was thought that the difference in life was due to some difference in heat treatment or hardening procedure. This was confirmed by hardness tests carried out with a Shore monotron machine.

In the case of the better tap, the hardness number ranged from 620 to 640, but in the case of the inferior one, the hardness number was in the region of 620 on one side, whilst on the other, the average hardness only amounted to 500, thus showing that the heat treatment was uneven.

The above may all seem very simple, and not differing from many cases which are met with in connection with steel heat treatment, but the point which the writer thought would probably be of interest to readers is this: During the etching of the specimens for micro-examination it was found that apart from the fact that the depth of etching varied according to the varying hardness areas (which is as one would expect) a peculiar etching design was brought about if the etching was carried out with a special reagent. This revealed very distinctly the lower hardness areas, as clearly shown in the photomacrographs. It occurred to the writer that this etching procedure might be of practical service use for rapidly determining uneven heat treatment, or hardness, in cases where it is not advisable or practicable to make hardness determinations.

The reagent consisted of 23 ml. of distilled water, 20 ml. concentrated hydrochloric acid, and 10 ml. concentrated nitric acid. The chemist will no doubt recognise the similarity of this reagent to aqua regia, but the important point to determine was the extent of dilution.



Aqua Regia of Proper Dilution Will Darken Improperly Hardened High Speed Steel. Light areas have monotron hardness number of 620 to 640; dark areas are only 500 hard, on the average

The details of etching procedure were: Immersion — for five or six seconds — of the specimens in water, the temperature of which ranged from 180 to 200° F., followed by immersion in the special etching medium (cold) for about ten seconds.

H. H. SHEPHERD
Chief Metallurgist, Crane, Limited

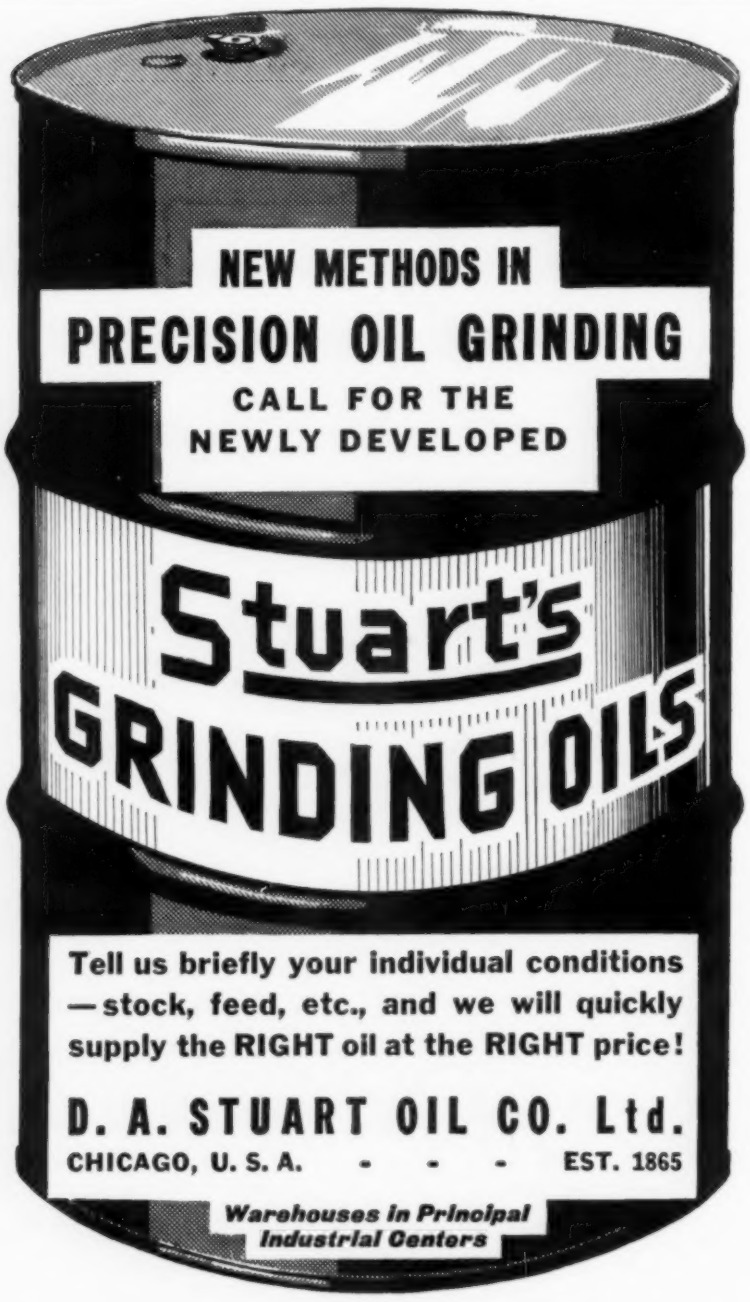
PERSONALS

A. G. C. Quay, formerly Cleveland district manager of sales for Union Drawn Steel Division, now holds a similar position with Moltrup Steel Products Co.

Ralph L. Freeman is now with Western Electric Co., Chicago, in the engineering department.

Elected president of Manufacturers' Association of Hartford County: **Fred G. Hughes,** past president, vice-president and general manager. New Departure Mfg. Co.

H. A. Schwartz, manager of research, National Malleable and Steel Castings Co., Cleveland, has been elected an alumni representative on the board of managers of Rose Polytechnic Institute, Terre Haute, Ind.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Watch For "STUART OILS" In Operation At Cleveland Machine Tool Show

Alexander R. Troiano (D.Sc. Harvard University, June 1939) has been made assistant professor of metallurgy in University of Notre Dame, replacing **Carl F. Floe**, who assumes similar duties at Massachusetts Institute of Technology.

Walter K. Graham, formerly with Republic Steel Corp., Cleveland, is now in the sales department of National Tube Co. in Dallas, Texas.

John J. Fitzgibbon, formerly in the research laboratory, International Nickel Co., is now with Whitehead Metal Products Co., Inc., New York City, in a sales capacity.

K. T. French has been appointed resident representative for the Toledo district for Allegheny Ludlum Steel Corp. **R. S. Ahlbrandt** has been made district sales manager of the Pittsburgh district.

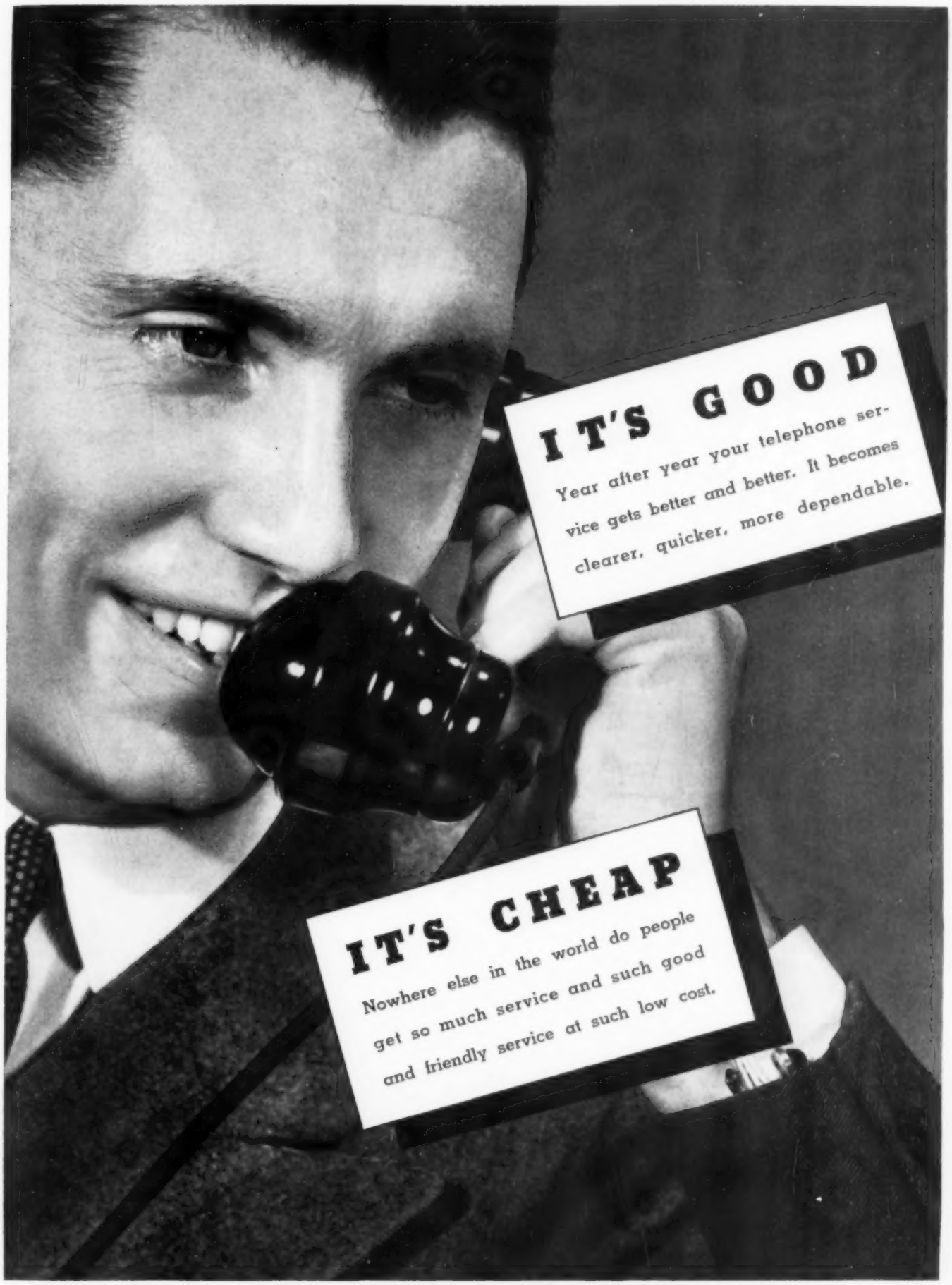
Awarded the first gold medal of the Japan Institute of Metals: **Kotaro Honda**, president of the Institute and of the Tôhoku Imperial University.

Frederick C. Hull is the first recipient of the new Westinghouse fellowship for graduate study in metallurgy at Carnegie Institute of Technology, Pittsburgh.

Elected president of the American Society for Testing Materials: **H. H. Morgan**, Robert W. Hunt Co., Chicago. **T. S. Fuller**, General Electric Co., Schenectady, and **J. L. McCloud**, Ford Motor Co., Dearborn, Mich., were among those elected to the executive committee.

William F. Walter, graduate of Lehigh University, has a position with Carnegie-Illinois Steel Corp., Duquesne Works, Pittsburgh.

Clarence W. Fabel has been made assistant metallurgist, Ordnance Department, Navy Yard, Washington, D. C.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BELL TELEPHONE SYSTEM

• The Bell System cordially invites you to visit its exhibits at the New York World's Fair and the Golden Gate International Exposition, San Francisco.

FATIGUE TESTS

(Continued from Page 140)

welds, produced by hand under practical conditions, limiting safe ranges are 0 ± 13,500 psi., 11,000 ± 11,000 psi., or 18,000 ± 9000 psi. — the last corresponding to a cycle ranging from 9000 to 27,000 psi. in tension. These strengths may be expected with widely different types of electrode, even when small gas holes or slag inclusions are present — as they commonly are — provided the deposit is free from gross slag inclusions and from "lack of fusion". Thus the limiting range of pulsating stress, from zero upwards, may be expected to be about 22,500 psi.

The fractures of butt welded joints occur through the deposited metal only when the deposits are somewhat weaker than usual or are unduly weakened by slag inclusions. More commonly the fatigue cracks start at or near the junction between the deposited metal and the parent metal of the plate — even when there is no apparent lack of fusion. The same location is found when the pieces are turned down to remove surface actions, and it appears that the limiting strength in fatigue is determined chiefly by the strength of the thin layer of parent metal subjected to the severe thermal treatment imposed by welding.

Corresponding figures for fillet welded lap joints with shallow double joggles are 0 ± 9000 psi. and for deep single joggles are 0 ± 4500 psi. respectively, which are both probably in excess of the corresponding values for riveted joints of ordinary qualities such as have served — and served well — in ship-building practice extending over several generations.

Butt welds made under the conditions prevailing in high class boilermaking practice give much higher limiting fatigue strengths (0 ± 25,000 psi.) up to nearly double the values quoted above for butt welds in structural work. They also break at the junction between deposited and parent metal, and the figures approach those for the rolled plate and are greatly superior to those estimated for riveted joints. These values justify a substantial reduction of thickness in boiler plates. This is very desirable, not only for economy and lightness, but also to reduce thermal stresses and other stresses arising from enforced strains rather than from pressure.

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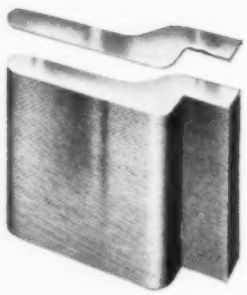
75 FOLDING ARMS
Made At One Time on the DOALL

Peters Machine Co., Chicago, stacked 75 pieces of .083" high carbon steel, tack welded the corners to form a solid block more than 6" thick. A layout line was scribed on the top sheet and the 75 parts were made at the same time on the DoAll, in 4 hours, or about 3 minutes each. Labor cost, 3 cents each.



RECORD SMASHING!

Contour Sawing, the new DoAll process of machining, is recognized as the fastest precision method of removing metal; cuts out internal and external shapes from any metal up to 10" thick.

Does work of 3 machines. DoAll is a moderately priced, rugged precision machine tool that replaces shaping, milling and lathe work on a large variety of jobs with enormous savings.

Used in large and small plants in 30 countries by such firms as Ford, Fisher Body, Cadillac, Baldwin Locomotive, Douglas Aircraft, U. S. Navy, International Harvester, General Electric, Westinghouse, Ace Tool & Die, Glenn L. Martin, etc.

Let a factory trained man bring a DoAll to your plant and show you what it does, what it saves on your own work.

FREE New Handbook on Contour Machining —100 pages of valuable metal working helps.

CONTINENTAL MACHINES, Inc.
1307 S. Washington Ave., Minn., Minn.

MP. 8
☐ Send data on the DoAll.
☐ Send Free Handbook.
Name .....
Address .....

CO-CR-W ALLOYS

(From page 137) troublesome tendency of steel tools to pick up flakes or threads of metal.

The last graph on page 137 gives the reflectivity of several metals with respect to various wave lengths in the range from 2,000 to 60,000 Ångström units. To a large extent, the interest in metal for reflective purposes is confined to the visible range of the spectrum, but the reflectivity in the ultra-violet band between 2,800 and 3,200 Å. is of interest for therapeutic and other reasons. While the cobalt-chromium-tungsten alloys lack some of the reflecting qualities of silver, they are frequently more suitable than silver because of their greater resistance to scratching and because they will not tarnish. Advantage is taken of this durable reflecting power in the manufacture of mirrors for microscopes and other physical apparatus.

The corrosion resistance of these alloys is excellent. While they are infrequently used solely for their exceptionally good resistance to corrosion, their stainlessness is of real value in applications involving a combination of both corrosion and wear.

They are immune to all ordinary corroding media and are highly resistant to many corrosive acids and chemicals. Hydrochloric acid attacks the alloys, but fruit juices, salt water, nitric acid, and many other corrosive chemicals have little or no effect.

Actual plant conditions must be simulated in order to determine the length of life of any metal when exposed to particular chemicals. The only real test is their life in service. Results obtained by laboratory tests and given in the table on page 136 will give an indication of the relative penetration of the cast and forged grades of stellite (No. 1 and No. 6, respectively) by some of the common chemical reagents. These results were obtained with ordinary laboratory reagents in glassware. In each case, the samples of the alloys were submerged for 15 hr. The concentration of the solution is expressed as per cent by weight, while the corrosion results are expressed as the rate of penetration in inches per month.

These alloys combine high reflectivity, permanence of finish, resistance to abrasion, and mechanical strength to a remarkable degree, probably to an extent unknown in any other material.

AN ADVISORY BOARD ON HEAT TREATING

The services of a group of experts in the heat treating field are at your disposal when you call on Flinn & Dreffein.

Our 32 years of furnace building experience have taught us the answers to many heat treating problems. Tribute to our knowledge is the fact that we have been called on to manufacture more furnaces for the sheet mill than any other furnace builder.

Our entire staff has but one thought in mind—to help you solve your heat treating problem the most efficient, most economical way. An inquiry regarding our service will put you under no obligation—and might result in a solution to your problem.

annealing ... billet heating ... bright hardening ... controlled atmosphere ... carburizing ... scale-free annealing ... drawing ... short cycle malleable annealing ... forging ... hardening ... normalizing ... continuous conveyor furnaces ... continuous pack and pair furnaces for sheet mills ... continuous normalizing furnaces for sheet mills.

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INDUSTRIAL FUEL EQUIPMENT
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FLINN & DREFFEIN
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308 WEST WASHINGTON ST., CHICAGO, ILLINOIS

AB POLISHERS

FOR METALLURGICAL LABORATORIES

Solve the problem of efficient, economical sample preparation. Vibrationless operation and selective speeds eliminate pitting. Interchangeable 8 inch diam. polishing discs increase peripheral speed latitude. Sturdy construction, comfort, and convenience have contributed to their unequalled popularity.

A-B STANDARD POLISHER

Selective speeds 575 and 1150 r.p.m. Vertical radial, and thrust ball bearing motor.

A-B LOW SPEED POLISHER

The ideal solution where slow speed polishing is required. Operates at 250 r.p.m.

ASK FOR YOUR COPY OF "THE METAL ANALYST"

Adolph I. Buehler

OPTICAL INSTRUMENTS • METALLURGICAL APPARATUS

228 NORTH LA SALLE ST. • • CHICAGO ILL.

TOOL STEELS of Reputation

William Jessop & Sons Genuine Yellow Label is the finest Carbon Tool Steel made.

It has been in continuous demand for over a century and a half.

A perfect Steel for Tools and Dies where freedom from risk in Hardening and Long Life are absolutely vital.

The name Wm. Jessop & Sons stamped in every bar is your assurance of Quality.

WILLIAM JESSOP & SONS

1774 **Inc.** 1939

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Agencies in all principal cities.

Lick the Tough Jobs

HEPPENSTALL COMPANY

PITTSBURGH · BRIDGEPORT · DETROIT

270 INCH SCALE LENGTH

SOUTHWARK TATE·EMERY 5-50

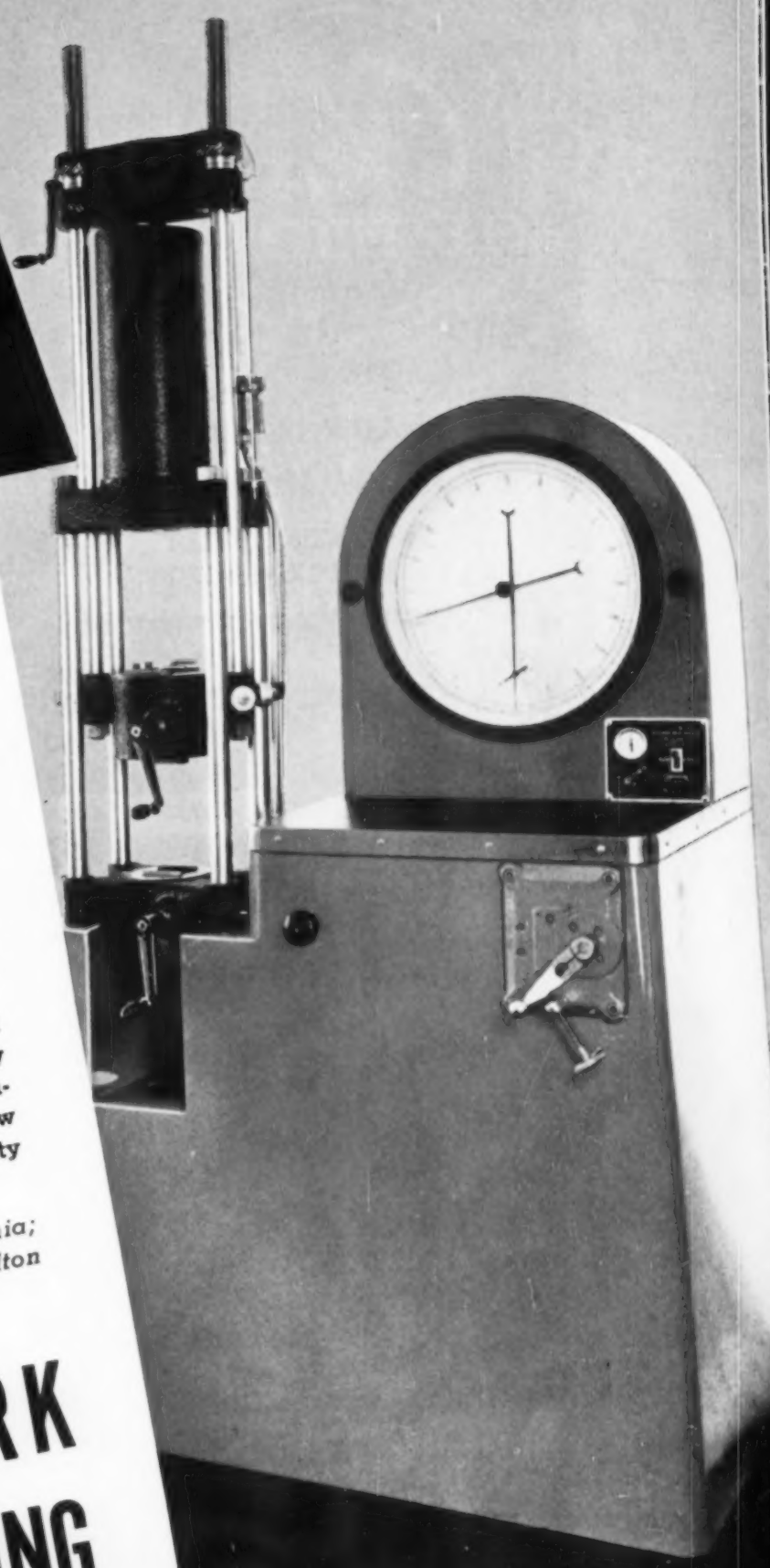
With a scale length more than four times longer than any other machine, the Southwark-Tate-Emery 5-50 makes possible easy and accurate dial readings.

A product of research, the 50,000-lb. capacity 5-50 embodies the latest Tate-Emery null method, servo-operated indicator combined with a lapped ram and cylinder unit of excellent construction.

Here is the ideal machine for the limited budget. Self-contained, and completely standardized, the 5-50 is extremely sensitive and accurate — especially in the low ranges. It is a Southwark-Emery quality machine for the medium price field.

Baldwin-Southwark Corp., Philadelphia; Pacific Coast Representative, The Pelton Water Wheel Co., San Franciso.

SOUTHWARK EMERY TESTING MACHINES



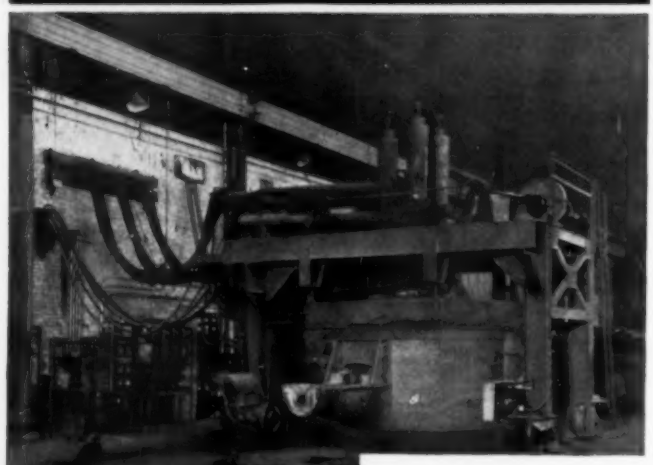
50,000-lb. Southwark-Tate-Emery Universal Testing Machine

Char
CARBURIZERS

★ LOW DUSTING LOSS
★ LOW SHRINKAGE
★ CONTINUOUSLY UNIFORM ACTIVITY

CHAR PRODUCTS COMPANY
MERCHANTS BANK BUILDING INDIANAPOLIS

Heroult ELECTRIC FURNACES



Type-10 Heroult Furnace with gantry-type removable roof for overhead bucket charging.

USE them for efficient melting and refining of all kinds of ferrous materials by either basic or acid process—including alloy, tool and forging steels, iron and steel castings. Any capacity from ½ ton to 100 tons; removable roof, chute, machine or hand charging.

AMERICAN BRIDGE COMPANY
General Offices: Pittsburgh, Pa.
Offices in the larger cities
Columbia Steel Co., San Francisco, *Pacific Coast Distributors*
United States Steel Products Co., New York, *Export Distributors*

UNITED STATES STEEL

(Continued from page 162)

High chromium steels transform incompletely in the upper portion of the intermediate temperature range. Those containing between 0.8 and 1.8% of chromium give two-stage transformation curves (probably due to a rapid partial intermediate transformation followed by a slow pearlite transformation). In these cases two points are plotted on the completeness-of-transformation diagram, one relating to the quantity of austenite transformed in the first stage (and associated by a dotted line with the completeness of transformation observed in the intermediate range) and the other relating to the total transformation observed.

The chromium steels illustrate the danger of comparing the transformation velocities of steels at one or two temperatures only. It happens that the chromium steels have a minimum in their transformation-velocity curves at the temperature at which the nickel steels have their maximum velocity. A comparison made at 1000° F. would therefore unduly stress the action of chromium. Conversely, a comparison made at 1200° F. would exaggerate that of nickel. The two elements, in fact, supplement each other. Chromium introduces a retarding effect at the temperature at which nickel steels would otherwise transform rapidly, whereas nickel removes the tendency of chromium steels to transform at high temperature as well as lowering the transformation velocity at all temperatures.

Perhaps the most striking conclusion from these studies is a realization of the very large changes of transformation velocity which result from comparatively small changes of composition, and the very high transformation velocities which occur in some steels in the intermediate temperature range. Although the specimens used have been quite small (0.11 in. diameter), it has often been impossible to quench them without some transformation occurring during the cooling operation, and it is clear that in these cases the commercial quenching of articles of ordinary size must result in very incomplete hardening.

In view of the depreciation of properties which accompanies transformation above the martensite point, it seems that improvements must often be possible as a result of modifications which decrease the rate of transformation.

High hardenability, it should be noted, has no value in itself, and, indeed, may sometimes be regarded as a disadvantage. Provided that the steel has a sufficiently low maximum transformation velocity to become fully martensitic at the rate of cooling possible in practice with the component being dealt with, the more readily it transforms under all other conditions to pearlite, the better.

Koehring Uses AMPCO METAL FOR GREATER WEAR AND SHOCK RESISTANCE

Properties Found ONLY In Ampco Metal

It's the *processing* that gives AMPCO its superiority. The "Ampco Phase" is not a mere catchword—but a unique step in the development of a better alloy. Comparative tests are convincing, and unfailingly reveal the longer wearability of AMPCO METAL — its greater resistance to shock—its greater wearability wherever stress and strain are involved.

These properties, processed into AMPCO METAL, are not found in any other bronze.

MORE than a decade ago, Koehring engineers investigated AMPCO METAL. Tests indicated its wear resistance and compressive strength to be far superior to that of other bronzes tested. As a result, the Koehring Company, makers of a world famous line of contractors' equipment, has standardized on AMPCO METAL ever since for all highly stressed bronze parts.

First Choice Wherever Metals Are Highly Stressed

Fortified with AMPCO METAL, the lower traction-shaft bushings on Koehring shovels run against hardened steel at a speed of 17 revolutions per minute and under loads ranging from 32,000 to 46,000 pounds. Hoist-drum bushings of AMPCO run against heat-treated steel at 35 revolutions per minute under loads up to 22,000 pounds. AMPCO METAL is also used for bushings and idler sprockets in connection with the chain-crowd mechanism . . . for saddle blocks on chain-crowds . . . for spiral boom trolley base bushings . . . drum bushings . . . and boom hoist drum bushings. Turntable roller bushings of AMPCO METAL carry the whole weight of the cab, boom and load. Throughout the Koehring line, wherever a bronze must have extreme wearability under stress and strain, AMPCO METAL has had the preference for many years. It will pay you to have all the facts on AMPCO METAL.

Write for File 40 — a bound volume of Ampco Engineering Sheets.

AMPCO METAL, INC., Dept. MP-8, Milwaukee, Wis.

AMPCO METAL

"The Metal without an Equal"

. . . distinguished by this mark.

reduces CLEANING COSTS 80%!

NO DUST
CORE RODS RECLAIMED
SAND SALVAGED

SAVINGS

11,500 pounds weight of casting
16,500 pounds weight of cores, rods, etc.
28,000 pounds total weight before cleaning

57 minutes cleaning time by PANGBORN CASTING WASHER
300 minutes cleaning time by former hand process
243 MINUTES SAVED BY USE OF PANGBORN CASTING WASHER

SAFETY

Operator always outside washing room during actual cleaning process . . . away from all water and spray . . . away from danger of being hit by core rods, gaggers, etc. NO DUST OR DIRT. No uncomfortable clothing or water helmets.

MAINTENANCE

Lowest cleaning maintenance. Water is reused over and over. Original supply may be replenished by rain water from roof of building. Sand is salvaged, reconditioned and reused. One company reports a sand saving of $2,000. per year. "Upkeep practically nil" comment of satisfied user after nine years continuous operation. *Write today for information.*

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GENERAL ELECTRIC CO. West Lynn, Mass.
AMERICAN LOCOMOTIVE CO. Schenectady, N. Y.
GLEASON WORKS Rochester, N. Y.
BUCYRUS-ERIE CO. S. Milwaukee, Wisc.
MARION STEAM SHOVEL CO. Marion, Ohio
CATERPILLAR TRACTOR CO. Peoria, Ill.
PENN STEEL CASTINGS CO. Chester, Penna.
WATERBURY-FARREL CO. Waterbury, Conn.

NOTE: Find out for yourself what users think of the Pangborn Casting Washer method of cleaning by water. Write NOW to any of the above concerns for first hand user opinion.

PANGBORN

WORLD'S LARGEST MANUFACTURER OF BLAST CLEANING AND DUST CONTROL EQUIPMENT

PANGBORN CORPORATION • HAGERSTOWN, MD.

STEWART

INDUSTRIAL FURNACES of all kinds

FORGING, HEAT TREATING, METAL MELTING, ETC.

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CAR TYPE FURNACES, CONVEYOR FURNACES and the STEWART GASIFIER

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A Stewart representative is located near you. Let us know and we will see that he gets in touch with you quickly.

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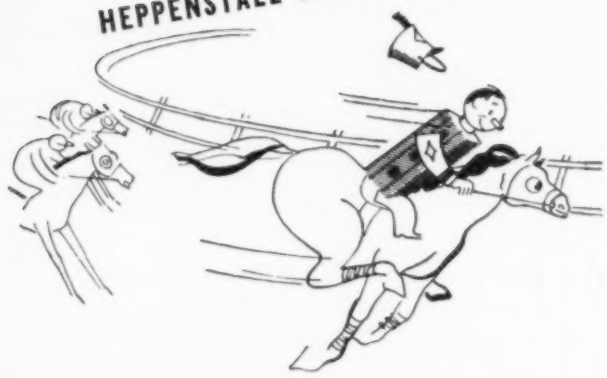
Always out in Front

HEPPENSTALL SHEAR KNIVES



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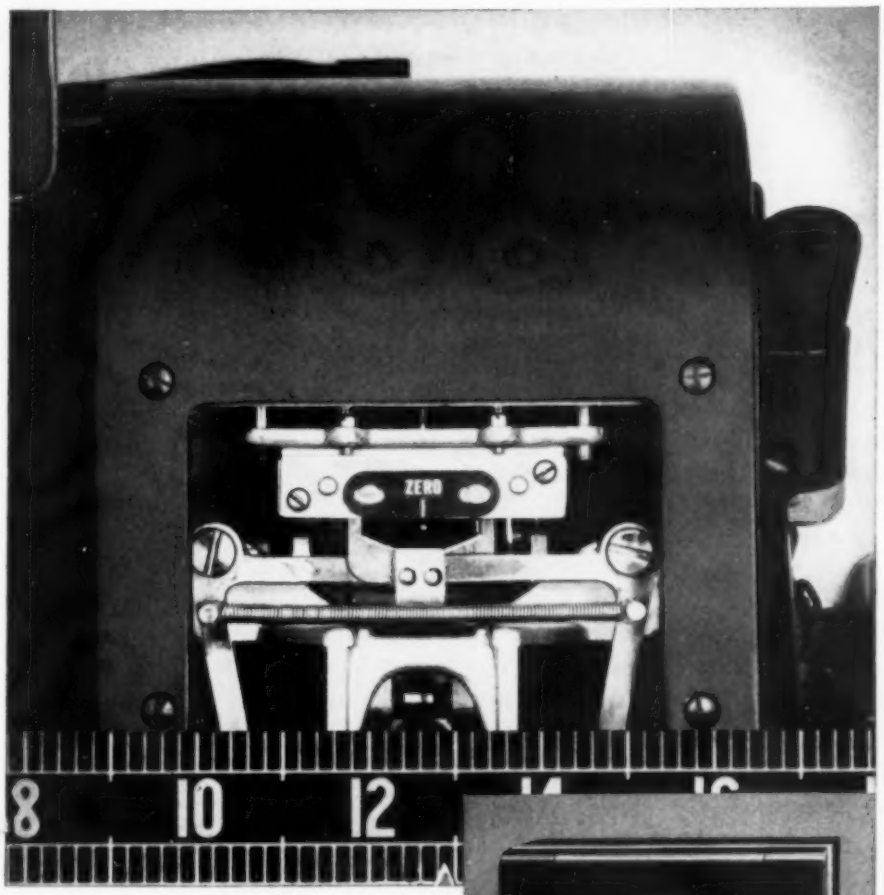
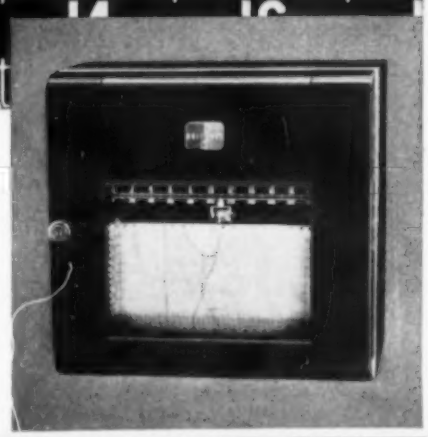
HEPPENSTALL COMPANY
PITTSBURGH · BRIDGEPORT · DETROIT

DUST-PROOF

galvanometer precision

Another feature of **BRISTOL'S WIDE-STRIP PYROMETER**
contributing to fine performance





CRAFTSMANSHIP
you can see at a glance!

Reflecting throughout the simplicity, beauty and perfection that identify the genius of the master craftsman, this Bristol's Wide-Strip Pyrometer possesses many other interesting features that you will want to know about. The following will be discussed in subsequent advertisements: (a) Circuit automatically standardized, (b) Electric balancing, (c) No lost motion, (d) Visible operating mechanism, (e) Extra wide 12¼ inch chart, (f) Duplex slide wire accuracy, (g) Large easy to read scale, (h) Automatic cold junction compensator.

IN THIS modern Bristol's Wide-Strip Potentiometer Pyrometer, the galvanometer is wholly enclosed. It is protected against dust not only by the gasketed instrument case, but also by an additional enclosure in which it is mounted.

While a Bristol's Wide-Strip should, if possible, be located in places where the atmosphere is clean, it can be installed, when necessary, amid any dusty and dust-filled surroundings. It is intended to withstand severe shop conditions.

The instrument case door may be opened in order to mark the charts, set the galvanometer zero, or for any other purpose—and still the instrument continues to operate, unaffected by any air currents that may be present. A window in the inner enclosure permits observing the galvanometer pointer and the associated operating lines.

These features and dozens more you will welcome because they make maintenance a minimum and assure easy servicing. For complete information, write for Catalog 1452.

THE BRISTOL COMPANY
WATERBURY, CONNECTICUT

Branch Offices: Akron, Birmingham, Boston, Chicago, Detroit, Los Angeles, New York, Philadelphia, Pittsburgh, St. Louis, San Francisco, Seattle. Canada: The Bristol Company of Canada, Limited, Toronto, Ontario. England: Bristol's Instrument Company, Limited, London, N.W. 10

BRISTOL'S
TRADE MARK REG. U. S. PAT. OFF.

Wide-strip Pyrometer

RECORDING ★ CONTROLLING ★ MULTIPLE RECORD MODELS

AUTHORS IN THIS ISSUE

W. A. Wissler writes with authority on the subject of Stellite, having been with Haynes Stellite Co. from 1917 to 1923, and since then with the Niagara Falls research laboratory of the parent company, Union Carbide & Carbon Corp. Electrochemistry was Wissler's original field and formed the basis of his master's degree obtained after graduate study at University of Wisconsin and Indiana University. Thus armed, he spent a year at the Brandywine Experimental Station of E. I. du Pont de Nemours & Co. and then became an instructor in chemistry at McGill University. Another year as research fellow at McGill preceded his connection with Haynes Stellite.

To his father, who died in 1937 after an eventful life as a pioneer in the development of high speed steel and in the mining and refining of tungsten, **Philip M. McKenna** owes his early interest in the chemistry and metallurgy of tool materials. His A.B. from George Washington University was supplemented by additional courses in physical chemistry at Columbia University and California Institute of Technology. Well-trained in laboratory, factory and mine, in 1913 he invented a process for separating nickel from cobalt, and in 1917 processes of purifying ferrotungsten. Following a decade during which he was engaged in the refining of tungsten ores, he went in 1928 to Vanadium Alloys Steel Co. as research director of the firm his father had helped found. In 1936 he was made vice-president, but two years later he decided to organize his own business in the rapidly expanding field of hard carbides, and McKenna Metals Co. is the result. He holds numerous patents on hard compositions for tool use, and is the author of several papers on refractory intermetallic compounds.

Familiar to readers of the *Transactions* should be the name of **Mary Baeyertz,** who, as research metallurgist of America's second largest steel plant, has contributed technical papers on such subjects as inclusions in stainless steel, oxidation of steel, and electrolytic etching. Miss Baeyertz has been at Carnegie-Illinois' South Works since 1931. Her undergraduate work was done at Smith College and her doctor's degree came from Columbia University in 1925.

John F. Perkins is also employed at the South Works, as pyrometric supervisor in the metallurgical department. His is the responsibility for calibration and maintenance of all the pyrometric equipment used throughout the mill. He has been at Carnegie-Illinois for 18 months and has had broad practical experience in his line.

William Wraith, who wrote the appreciation of Mr. Mathewson on page 139, is Executive, Inspiration Consolidated Copper Co., and Andes Copper Mining Co., both subsidiaries of Anaconda. He was Mr. Mathewson's principal assistant at the Washoe plant in Montana during the pre-War times he describes.

John F. Perkins

William A. Wissler

Mary Baeyertz

Philip M. McKenna

O FURNACE IS BETTER THAN ITS ALLOY PARTS

"YER LICE HAS GOT TO LIVE"

WE were once asked by a busy steel executive, whose guest we were, to quiz two mill-town mayoralty candidates, each seeking campaign contribution, and underwrite the winner. We backed the current incumbent, a proven push-over, but hedged with a generous donation to probable (Republican) loser. Our ignorance of local conditions demanded an aggressive approach, so we berated the then ensconced (and later re-elected) parasite for running a lousy loose town over-run with hand-books, harpies, hoodlums and harlots.

"I RESENT the inference but admit the charges", says His Honor, "but,—yuh ain't heard of no stick-ups, shootin's or shake-downs in *my* administration," then, —proudly, "in practical politics,—yuh know,—Yer Lice Has Got To Live. You can't exterminate 'em. If you fumigate 'em into the next county, they toss 'em right back with extras. When they're hungry they're tough, so we let 'em feed light on hand-books, bingo, slot machines and small rackets, and,—they don't give us no headlines." Snaring another Stogie, he continued,—"Some Voters is born to chisel,—just can't sell themselves or their stuff on an equal footing. Mebbe it's that way in your business too?"

WE admit "Yer Lice Has Got To Live"—in any business,—but the *smart guys don't feed 'em.*

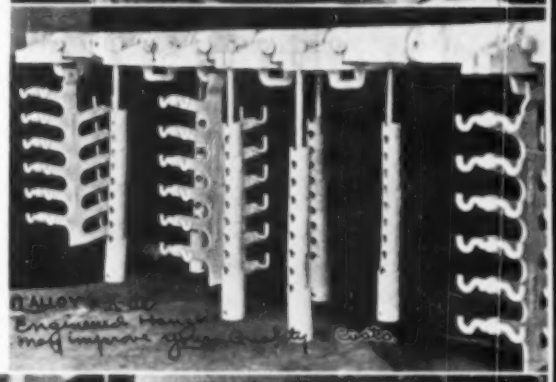
ENGINEERS point out the outstanding, patented, *design* superiority of G.A. SPIRALINK cast-non-stretching furnace conveyor-belt-hearth. Seven leading Furnace Builders use it as standard equipment, because it is the only self aligning, load-equalizing, belt made. All individual link belts carry the entire load on the shortest links, or "crank-shaft" the pins. *Now here,* we announce "SPIRALINK JR.", a new type of Spiralink, (HHH Pats. Pend.) with ONLY TWO INCH PITCH, weighing from eight to ten lbs. per sq.ft., to replace those stretchy-arsy-versy crocheted wire belts, (except in Pretzel Factories).

RARELY is a photograph enlarged a thousand times, rarer, perhaps, without the photographer's knowledge. I was surprised to find my sky-view (above) as the theme-center of the 7 panel 110 ft. photo-mural frieze, depicting American Civil Aviation, in the AVIATION building at the N.Y. World Fair. It shows the 1939 migration of Northern Birds on the mile square Miami Airport. Foreign magazines ran it labeled "Proof of U.S. leadership in Private Aeronautics". When they start making these canvas-kites in strong FIREPROOF Stainless Steel, we'll *have* Metal PROGRESS.

SMILING, able, Mother of two sons and a coloratura Soprano is Mrs. Florence Boswell, Cleveland, who has 900 flying hours on her Cessna, including a hop to Cuba,—dropped in for a week end aboard the Guardian. Her boys bait their playmates with "Our Ma is a better man than your Pa".

GENERAL ALLOYS particularly solicit your inquiries for carburizing containers from the largest GAS CARBURIZING MUFFLES to better retorts of all types. There, too, have been many improvements in Pots and Boxes, which are holding their own surprisingly well.

"THE most remarkable ALLOY PERFORMANCE in any continuous MALLEABLEIZING Furnace ever built" is a conservative statement on the 100% G.A. equipt "HOT BUGGY" Surface Combustion Furnace at Jamestown, N. Y. If you make Malleable you OWE YOURSELF knowledge of this job which is FREE FROM "GRIEF".

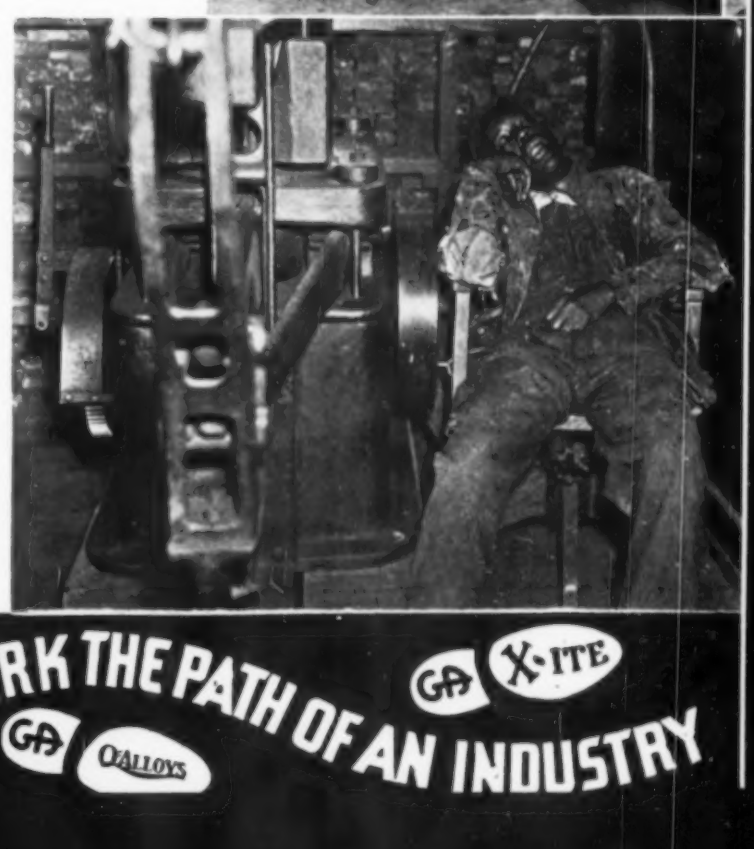


IF you feel like hanging anything in a hot-spot besides politicians, G.A. Engineers specialize on hangers for unusual requirements, (see Photo). If you want to save-with-safety on any Alloy job, G.A. ENGINEERING can help.

YES Sir! Metallographers *are* photographers. This photo "Fatigue Testing in Dixie", by E. M. Whelchel of Am. C. I. Pipe Co., Birmingham, proves it. Also asleep are many white and pleasingly tanned Gentlemen who erroneously believe X-ite and Q-Alloys will cost more than far inferior stuff they are using.

WE'VE had our *thrills* with Planes, Boats, 'Chutes, Motorcycle and Auto Racing, but the HIGH SPOT is a ride we took last week from lower 2nd Ave. to 21 W. 52nd N.Y.C.,—to win a 2 A.M. bet,—on a "MOTOR-SCOOT".

H. H. HARRIS



THE FOOTSTEPS OF GENERAL ALLOYS MARK THE PATH OF AN INDUSTRY

★ BUY AMERICAN ★

INDUSTRIAL FURNACES FOR EVERY PURPOSE...

For many years the American Electric Furnace Company has been pioneering, developing, manufacturing and shipping industrial furnaces to all parts of the world.

We have solved many difficult problems, and are continually solving others as the demands of industry present them. We may be able to solve your problem...at substantial savings. Why not write us today and take advantage of our experience?

We manufacture furnaces for:

Air Tempering
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Annealing
Aluminum Melting
Brass Holding
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Carburizing
Continuous Process
Cyaniding
Drawing
Enameling
Forging
High Speed Hardening
Lead Hardening
Nitriding
Normalizing
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Preheating
Salt Drawing
Special Process

AEF

American Electric Furnace Co.
30 VON HILLERN ST.
BOSTON, MASS.
All Types Industrial Furnaces

PURE CARBIDE-FREE
METALS

Tungsten Powder	97-98%
Pure Manganese	97-99%
Ferro-Chromium	60%
Pure Chromium	98-99%
Ferro-Tungsten	75-80%
Ferro-Titanium	25%
Ferro-Vanadium	35-40%

(1% Silicon)

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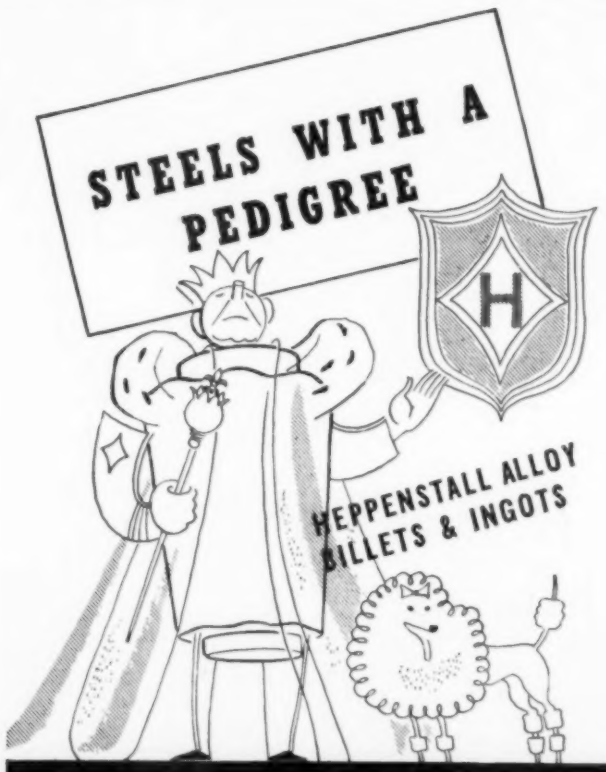
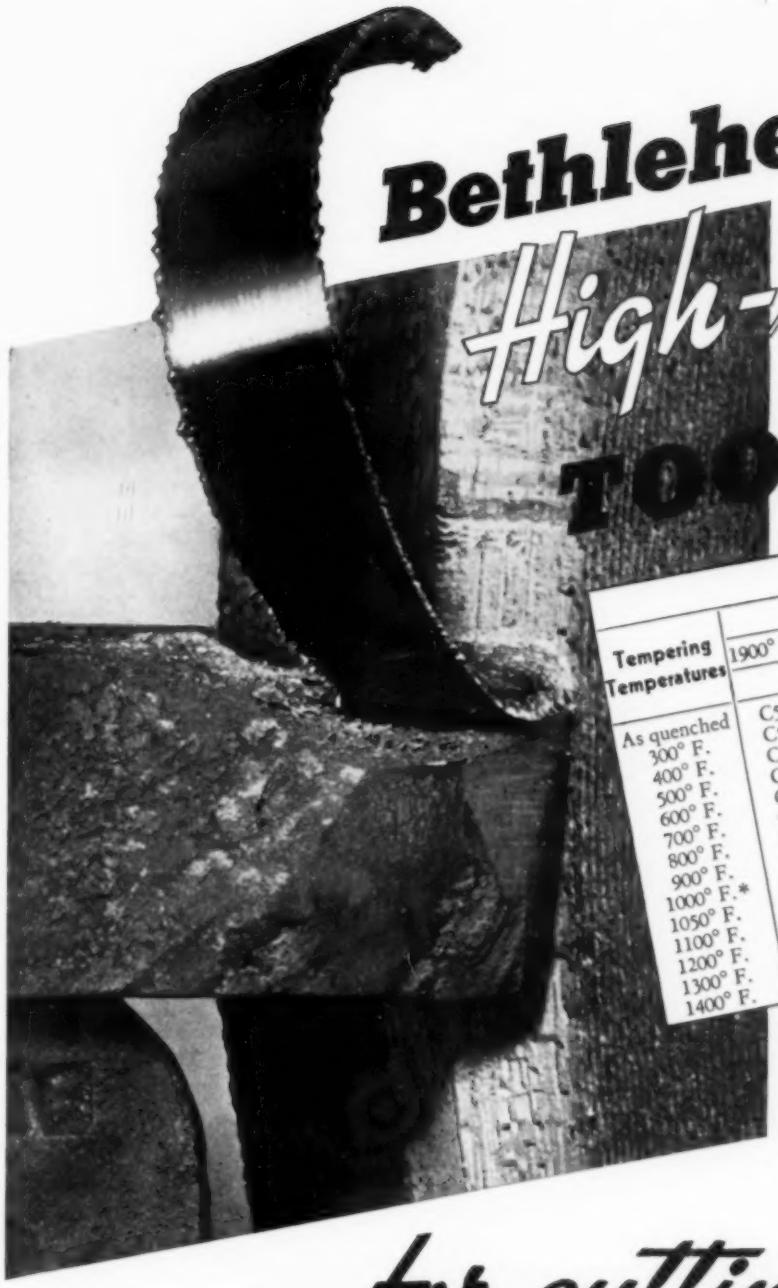


HEPPENSTALL COMPANY
PITTSBURGH · BRIDGEPORT · DETROIT

Bethlehem Special *High-speed* TOOL STEEL



Tempering Temperatures	OIL-QUENCHED SERIES — Quenching Temperatures — Rockwell Hardness Values						
	1900° F.	2000° F.	2100° F.	2200° F.	2300° F.	2350° F.*	2400° F.
As quenched	C59	C61	C63	C65	C65	C66	C66
300° F.	C59	C61	C63	C65	C65	C65	C65
400° F.	C59	C60	C62	C63	C64	C64	C64
500° F.	C58	C59	C60	C61	C62	C62	C63
600° F.	C57	C58	C60	C61	C61	C61	C62
700° F.	C57	C58	C59	C60	C61	C61	C61
800° F.	C57	C57	C59	C60	C61	C61	C61
900° F.	C57	C58	C60	C61	C62	C61	C61
1000° F.*	C57	C58	C61	C62	C62	C63	C63
1050° F.	C58	C59	C61	C62	C64	C64	C64
1100° F.	C47	C59	C61	C62	C64	C64	C64
1200° F.	C37	C49	C53	C55	C64	C64	C64
1300° F.	C32	C39	C44	C45	C57	C57	C58
1400° F.		C33	C33	C36	C47	C47	C47
					C36	C37	C37

Based on 1-inch round, 2 1/2-inch long specimen of Bethlehem Special High-Speed Tool Steel.

*Usually recommended for general purpose cutting tools.

...for cutting efficiency

BETHLEHEM High Speed Tool Steel is backed by 39 years of outstanding service on every type of grueling cutting job. It is a tried-and-proved standby for:

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3. Boring Mill tools
4. Slotters
5. Shaper tools
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7. Hobs
8. Milling Cutters
9. Broaches
10. End mills
11. Reamers
12. Planer tools

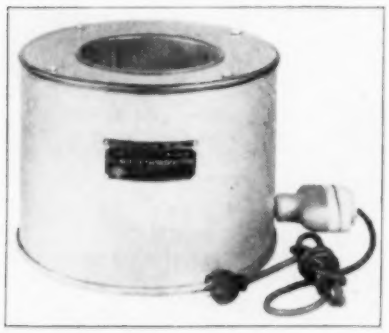
Wherever there's a cutting job of any kind, you'll find Bethlehem Special turning in an efficient economical performance.

A copy of the Bethlehem Tool Steel Guide will aid you in selecting the exact grade of Bethlehem Tool Steel best-equipped to handle your particular job. Write Bethlehem Steel Company, Bethlehem, Pa., for your copy.

BETHLEHEM STEEL COMPANY

BETHLEHEM STEEL

The Gordon Type 1100 Portable Electric Furnace



This unique portable electric furnace designed for use at temperatures below 1100 deg. F. For use with drawing salts and oil tempering baths.

Furnace only $75.00
Control Rheostat and Thermometer extra

Exceedingly economical. Power consumption only 900 watts.

Size 6¾ in. inside dia. by 6 in. deep

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Single Hole

Double Hole Oval

Double Hole Round

Fish Spine Beads

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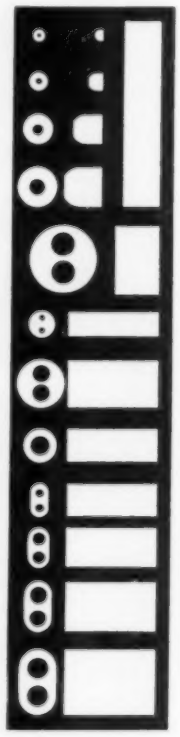
Asbestos String



Prices on request

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